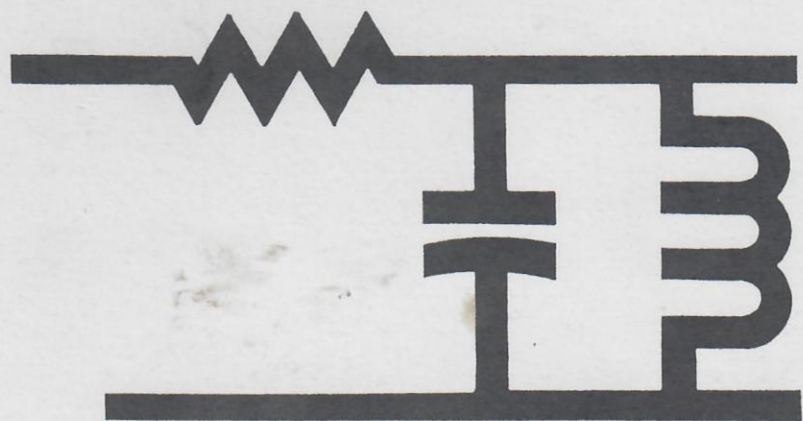




Ed-Lab

ANSWER MANUAL

ELECTRICITY - ELECTRONICS BOOK I



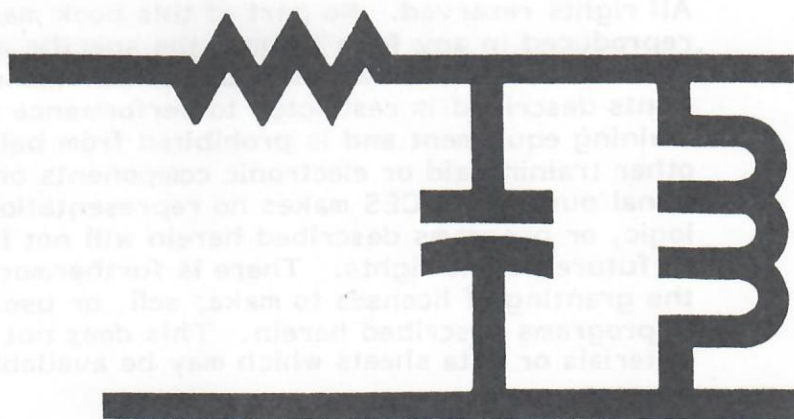
CES INDUSTRIES, INC.



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ANSWER MANUAL

ELECTRICITY - ELECTRONICS BOOK I



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ELECTRICITY-ELECTRONICS BOOK I

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Printed in United States of America

INTRODUCTION

The study of Basic Electricity and Basic Electronics usually includes a dual learning process: 1) Theoretical Study of Concepts and 2) Hands-On Practical Experimentation. The Theoretical Study can consist of Instructor Lectures in the traditional manner, or Self-Study by using a variety of reference materials including text books or audio visual resources in an Individual Instruction or Self-Paced procedure.

The Ed-Lab 650 Training System provides the means for the Circuit Experimentation. The add-on Ed-Lab 101 Prototype Breadboard provides a means for student experiences with a variety of components and circuit board assembly. The Ed-Lab 650 manuals contain the experiment procedures plus the technical explanations needed.

The Ed-Lab 650 program starts with Book I, Unit 1, D.C. Circuits. The experiments in Unit 1 cover the Series Circuit, Meter Reading, Current-Voltage and Resistance Calculations, Series and Parallel Circuits, Kirchhoff's Circuit Laws, and other topics in D.C. Circuits. Unit 2 covers Diodes, Photocells, Switches and other circuits and devices. Unit 3 covers AC Circuits including variations with Frequency and Inductors and Capacitors.

The first experiment in Unit 1 is the Series Circuit and Ohm's Law. The Circuit consists of a Voltage Source (E) and a series Resistor (R) and a series meter to indicate a measure of the Current (I). Using the known Resistance (R) and the measured current (I), the Voltage (E) can be calculated using Ohm's Law as $E = IR$. The experiment manual includes both experiment procedures and the descriptions necessary to understand and perform the experiment.

BACKGROUND CONCEPTS

Certain background information and theory in basic electricity is in order. This material can be provided in Lectures or in Reference Materials which are listed later. These background topics or modules include:

Nature of Electricity, Magnetism, Electrical Components and Mathematics for Electronics. Details of these topics are listed on the following page.

These topics cover a background in the concepts of electricity.

However, it is the suggestion in this program that the student be scheduled for hands-on experimentation as soon as possible - within the first week or the first few days - or the first couple of hours. Understanding abstract concepts is difficult and time consuming. The suggested start of this electronics program is that after a brief introduction, the student run an experiment on a simple series circuit (experiment No. 1). He connects the EMF or Voltage Source to a Resistor and to the Meter. He learns to read the Meter (current), observes the effects of changing to higher and lower resistors, observes overscale readings on the meter, reviews schematic diagrams, pictorials and components symbols, prepares a test report, and calculates the applied Voltage based on the resistor used and his current reading, enters data in tables, and compares calculated results based on various tests using different resistors. It is suggested that the background material required be explained in the context of each experiment that the student performs. Magnetism explains the operation of the meter, Color Codes identify the values of the resistors, Current flow is related to electron flow and the atom, etc. It is further suggested that discussions of static electricity and magnetism and electromagnetism be kept to the minimum necessary at the start of the program and to be covered in more detail only when appropriate.

The concept here is that the student will better understand the material in electronics when explained in relation to hands-on experiments and observations.

BACKGROUND TOPICS IN CONCEPTS OF ELECTRICITY

NATURE OF ELECTRICITY

Static Electricity, Amber, Glass Rod (Silk), Resin Rod (Fur), Positive and Negative Charges, Attraction, Repulsion, Pith Balls, Atoms, Electrons, Conductors, Insulators, Electric Field Electrostatics, Electric Flow or Current Electromotive Force (EMF) and Primary Battery Cell, Resistance of Materials and relationship of Resistance, EMF, and Current.

MAGNETISM

- (a) Lodestone, Magnet, Magnetism, Magnetic Fields, Poles, Attraction and Repulsion, Compass.
- (b) Electromagnetism, Current generating a Magnetic Field, Electromagnetism, Motion of Conductor in Magnetic Field and Generator, Current in Conductor in Magnetic Field and Motor, Current in Conductor in Magnetic Field and Current Meters, Buzzers, Bells, Solenoids.

ELECTRICAL COMPONENTS

Resistors, Wirewound, Carbon, Fixed, Variable, Wattage, Color Code, Schematics, Pictorials, Switches, Battery, Concept of the Continuous Circuit, Fuses, Appliances, Electrical Power/Heat/Light, Energy, Electrical Instruments, Multimeter, Soldering, Circuit Boards, Wire Sizes, Tools, Circuit Assembly, Survey of Applications/Industry-Consumer-Communications-Military-Computer, Survey of other Components/Inductors, Capacitors, Transistors, Integrated Circuits, Vacuum Tubes, Microphones, Loudspeakers, Antennas.

MATHEMATICS FOR ELECTRONICS

Addition, Subtraction, Multiplication, Division, Calculators, Ohm's Law, Volt, Ohms, Amperes, Milli-amperes, Microamperes, Kilohms, Megohms, Millivolts, Solutions for E, I, and R.

BOOK I ELECTRICITY-ELECTRONICS ERRATA & CLARIFICATION SHEET

UNIT I

(FOR EDITION DATED 1974, 1976)

EXP. No. 1

page 5: Bottom left, change THIS CALE, to THIS SCALE

page 7: Fourth line change 10^{-3} to 10^3 .

page 7: Seventh line, change $E = I \times R = (470... \text{ etc})$ to
 $E = I \times R = (470... \text{ etc})$

page 8: Six lines from bottom; add note

$E = I \times R = (8.5\mu\text{a})(1\text{M})$ NOTE: The microamp and megohm cancel in the calculation.

page 9: Step 3: first line, change 9 volts to 8 volts

EXP. No. 2

page 2: In table, change 32K to 33K

EXP. No. 3

page 3: Bottom answer, change $R_T = 320\text{K}$ to $R_T = 320\text{Kohms}$

EXP. No. 11

page 1: 4 line up from the bottom, change $R_1 = 4.7\text{K}$ to $R_1 = 15\text{K}$

EXP. No. 12

page 5: In table column 2; change 100K POT to 1M POT

page 5: Three lines up from bottom; change 1K POT to 10K POT

EXP. No. 15

page 2: Change question 1 to: 1. What does the transistor do in this circuit?

EXP. No. 17

page 4: Question 2; change R_B to R_p

EXP. No. 22

page 1: Six lines up from the bottom change Unknow, to Unknown

UNIT II

EXP. No. 4

page 3: On schematic/resistor to ground; change 10K to 3.3K

UNIT III

EXP. No. 2

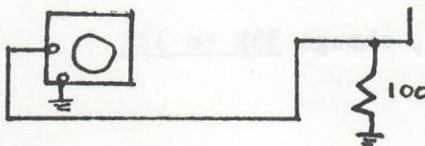
page 4: Question 1, change to read: When X_L is equal to 1K (same value as the resistor) the output voltage across the resistor is equal to the voltage across the inductor. At what frequency is X_L equal to 1K ? The output voltage across the resistor is not half the input voltage at this frequency because of difference in phase. The actual output voltage is equal to the input voltage divided by $\sqrt{2}$. This is discussed and explained in experiment #13.

UNIT III
EXP. No. 3

page 5: Question 3 change to read: When X_c is equal to the resistance (1K), the output voltage is equal to voltage across the resistor. At what frequency is X_c equal to 1000 ohms? As in the previous experiment the voltage output at this frequency is $\frac{V_{in}}{2}$.

EXP. No. 7

page 1: On both Schematics Figure 7-1 and Figure 7-2, add a 100 ohm resistor from the output of Signal Generator to ground.



EXP. No. 14

page 2: Fourth line, change $Z = \sqrt{R^2 + (V_L - V_C)^2}$ to $Z = \sqrt{R^2 + (X_L - X_C)^2}$

page 3: Paragraph 3 should read: Is the circuit Inductive Reactance or Capacitive Reactance greater at this frequency?

page 5: Line 5, change "Experiment No. 11" to "Experiment No. 12".

page 6: Second line, change $V_x = (V_c - V_L)$ to $V_x = (V_L - V_c)$

Fifth line, change $V_T = \sqrt{V_R^2 + (V_c - V_L)^2}$ to $V_T = \sqrt{V_R^2 + (V_L - V_c)^2}$

EXP. No. 15

page 2: First line, change "At the frequency" to "At this frequency"

page 4: First Column of graph should be changed to:

SET	ADJUST	READ
Frequency KHz	V input	V output R = 100 ohms
5.0	5	
5.2	5	
5.5	5	
5.7	5	
6.0	5	
6.2	5	
6.5	5	
6.7	5	
7.0	5	
7.2	5	
7.5	5	
7.7	5	

EXP. No. 16

page 1: Fourth line from bottom; change to read:
(i.e. for L = 56 mhy and C = 0.01 mfd; $f_r = 6.725$ Hz)

BOOK I ELECTRICITY-ELECTRONICS ERRATA & CLARIFICATION SHEET
(FOR EDITION DATED 1981)

UNIT I
EXP. NO. 1

page 3: In the formula for current, at the bottom of the page, change
 $\frac{8 \text{ volts}}{2 \text{ ohms}} = 4 \text{ amperes}$ to $\frac{6 \text{ volts}}{3 \text{ ohms}} = 2 \text{ amperes}$

EXP. NO. 16

page 1: 12 lines up from bottom, change V is in Volts to E is in Volts

UNIT III
EXP. NO. 6

page 4: In Procedure Step 9, change $\tau = R-C$ to $\tau = R \cdot C$

EXP. NO. 12

page 7: In Procedure Step 9, change $\frac{1}{2\pi (2 \cdot 10^3) (0.01 \cdot 10^{-6})}$
to $\frac{1}{2\pi (2 \cdot 10^3) (0.01 \cdot 10^{-6})}$

EXP. No. 14

page 5: Line 5, change "Experiment No. 11" to "Experiment No. 12".

EXP. No. 15

page 2: First line, change "At the frequency" to "At this frequency"

REFERENCE TEXTS INCLUDE:

Buban & Schmitt; Understanding Electricity & Electronics, McGraw-Hill, 1975

Tepper; Basic Radio, 1 to 7, Hayden, 1973

Mileaf; Electricity 1 to 7, Hayden, 1967

Rutkowski; Solid-State Electronics, Howard W. Sams, 1975

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14. R - L - C Phase Characteristics
15. Series Resonance
16. Parallel Resonance
17. Resonance Tuned Radio
18. Frequency Response Tracer

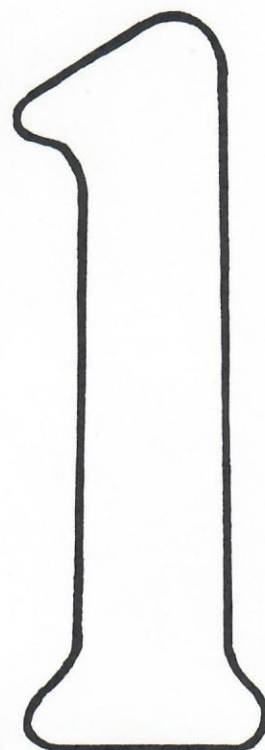


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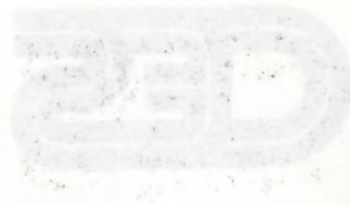
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BASICS and D.C. CIRCUITS

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BASIC and D.C. CIRCUITS

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UNIT NO. _____
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SERIES CIRCUIT & OHM'S LAW

A simple SERIES CIRCUIT consisting of a Voltage Source, Resistor and MICROAMMETER is studied. The METER is read. VOLTAGE is calculated. It is demonstrated that readings and calculations will DIFFER due to Tolerances of Components and METER and Reading Accuracy.

2.

Current (I) = 21 microamperes

(Since we can read to half a division, readings should have decimal point and one more digit)

4.

ENTER DATA

INPUT CONDITION		OUTPUT	
(A)		(B)	
RESISTORS USED	(R)	(I)	Enter data here CURRENT (Microamps)
470K		21.0	
1M		10	
4.7M		2.0	
100K		Reads over Full Scale	
56K		Reads over Full Scale	

6. The meter will read "TOO HIGH" with Resistors: 100K and 56K.

7. Resistor resulting in the lowest current is: 4.7M

8. Higher resistances will cause smaller current to flow in the circuit?
ANSWER: Current becomes Lower

9. As the resistance decreases the current will get higher?
ANSWER: Current becomes Higher

11. $+V2 = (10) \mu a \times 1M = 9.0 \times 1 \text{ volt}$

+V2 = 10 VOLTS

SERIES CIRCUIT & OHM'S LAW

13. The voltage obtained in 11 above is between 9 and 10 volts?

ANSWER: YES

EXERCISES:

1. Calculate the voltage based on the current reading for 470K resistor.

$$I (470K) = \text{Current for 470K resistor} = 20 \text{ microamperes}$$

$$E = IR = (21 \mu a) (470K) = (21 \mu a) (.470M) = (21)(.470) \text{ volts}$$

$$E = 9.87 \text{ volts}$$

2. Calculate the (+V2) voltage based on the current reading for the 4.7M resistor.

$$I (4.7M) = \text{Current for 4.7M Resistor} = 2 \mu a$$

$$E = IR = (2 \mu a) (4.7M) = (2)(4.7) \text{ volts}$$

$$E = 9.4 \text{ volts}$$

3. How do the voltage calculations compare with each other based on the 1M, 470K and 4.7M current measurements.

$$\text{For 1M} \rightarrow E = 10V \quad \text{For 470K} \rightarrow E = 9.87 \quad \text{For 4.7M} \rightarrow E = 9.4V$$

INSTRUCTOR NOTES The percent difference is calculated as follows:

$$\% \text{ Difference} = \frac{10 - 9.4}{10} \times 100\% = \frac{0.6}{10} \times 100\% = 6\%$$

Since the resistors in the Ed-Lab 650 have a 5% tolerance and meter tolerance is 2% this difference is to be expected in experiments.

4. Calculate the Source Voltage E using Ohm's Law for the following sets of data.

R	I	Calculate $E = I \times R$
1M	45 μa	$(45 \times 1) = 45 \text{ volts}$
56K	35 μa	$(35 \times .056) = 1.9 \text{ volts}$
100K	15 μa	$(15 \times .1) = 1.5 \text{ volts}$

SERIES RESISTORS

The total resistance of several resistors connected in series is calculated. The resistors are connected in series and the current flowing in the series combination is measured. The result is plotted on a curve to demonstrate that the series resistances are equal to a single resistor equal to the sum of the resistors.

2. Current reading for 470K, 470, and 56K resistors in series.

$$I \text{ (for 3 Series Resistors)} = 10 \text{ Microamps}$$

3. Current Reading for 1 Megohm resistor taken in experiment #1.

$$I \text{ (for 1M resistor from experiment No. 1)} = 10 \text{ Microamps}$$

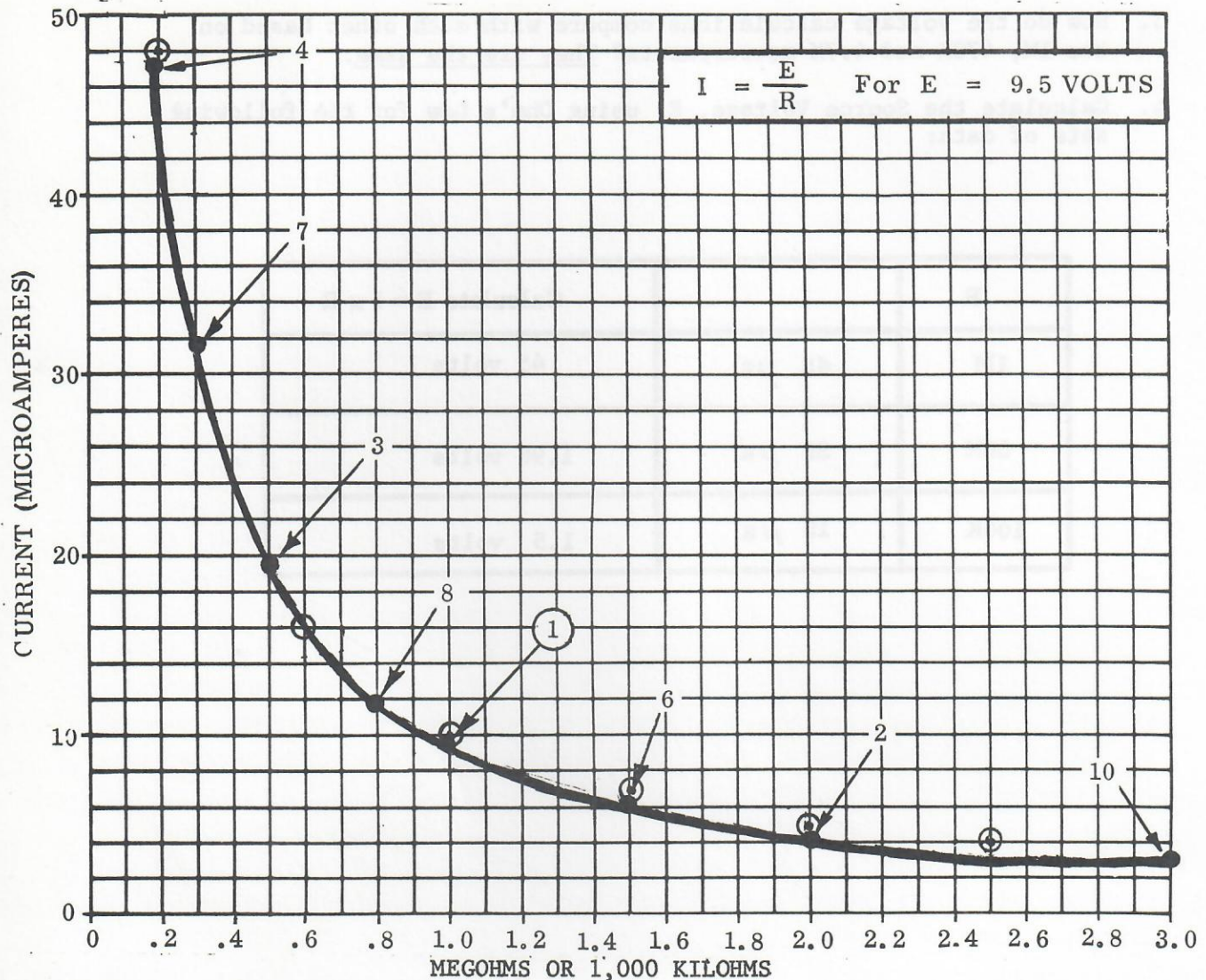
4. Both current readings recorded in steps 2 and 3 should be the same because the reading recorded in step 2 is the current through $470K + 470K + 56K = 996K$ and the reading in step 3 is the current through 1 Megohm or 1000K resistor. Since these resistances are nearly equal to the current for both circuits will be nearly equal.
5. Tabulation of Measured and Calculated Current for various series resistor combinations.

A			B	C
RESISTORS			MEASURED CURRENT	CALCULATE R_T
R1	R2	R3	in Microamps	$R_T = R_1 + R_2 + R_3$
470K	470K	56K	10.0 μ amps	1M
470K	470K	1M	5.0 μ amps	2M
470K	1M	1M	4.0 μ amps	2.5M
470K	100K	33K	16.0 μ amps	600K
470K	1M	22K	7.0 μ amps	1.5M
100K	100K	1K	48.0 μ amps	200K
100K	56K	15K	over scale	171K
56K	33K	22K	over scale	111K
15K	32K	10K	over scale	57K

← rounded off 996K
← rounded off 1.94M
← rounded off 2.47M
← rounded off 602K
← rounded off 1.492M
← rounded off 201K

SERIES RESISTORS

9. Curve of Measured Values and Calculated Values of Current for each Series Resistor.
⊙ Points from table on previous page.



10. Comparison of the Measured and Calculated Currents plotted on the graph of step 9. The two curves are very close to each other. The only variations that should be noted between the calculated and measured curves is that the measured curve may be shifted slightly upward or downward depending upon the actual value of +V2 on the trainer.

EXERCISES:

- Calculate the (+V2) Voltage based on the current reading for the 470K Resistor. $E = I \times R = 21 \mu\text{ amps} \times 470\text{K ohm} = 9.87 \text{ volts}$
- Calculate the (+V2) Voltage based on the current reading for the 4.7M Resistor. $E = I \times R = 2 \mu\text{ amps} \times 4.7\text{M} = 9.4 \text{ volts}$

SERIES RESISTORS

3. How do the voltage calculations compare with each other based on the 1M, 470K and 4.7M measurements? They are the same.
4. Calculate the Source Voltage, E. using Ohm's Law for the following sets of data:

R	I	Calculate $E = I \times R$
1M	45 μa	45 volts
56K	35 μa	1.96 volts
100K	15 μa	1.5 volts

PARALLEL RESISTORS

The total resistance for two resistors connected in parallel are calculated using a formula. The expected current is then determined. The current using the two parallel resistors is then measured and compared. The sum of the conductances and the parallel formula are both used to calculate the equivalent resistance of the two resistors in parallel.

2. Using the curve of Resistance versus Current in experiment 2 we arrive at a Current for 320K of:

$$I \text{ (FOR 320K FROM GRAPH)} = 31 \mu a$$

3. Using Ohm's Law to calculate the expected current

$$I = \frac{E}{R} = \frac{+V2}{320K} = \frac{(+V2)}{.320M} = \frac{(+V2)}{(.320)} \text{ Microamps}$$

$$I = \frac{10}{.32} \text{ MICROAMPERES}$$

$$I \text{ (FOR 320K OHM'S LAW)} = 31.25 \mu a$$

4. The measured current for the two parallel resistors is:

$$I \text{ (MEASURED)} = 31.5 \mu a$$

5. A comparison of the currents derived from the methods in steps 2, 3, & 4, show that the measured current (step 4) and the current from the graph (step 2) are the same. This makes sense since the measured curve and the theoretical curve agree exactly at the 320K point. The current calculated using Ohm's Law is 31.25 μa .

PARALLEL RESISTORS

EXERCISES:

1. If a large resistor and a small resistor are in parallel, is the equivalent resistance large or small?

The equivalent resistance will be small. If the large resistor is very much larger than the small resistor (100 times or more) the effect of the large resistor will not be noticed at all.

2. Calculate the Equivalent Resistance for the following parallel resistors.

GIVEN			CALCULATE
	R1	R2	R _T
1.	470K	470K	235K
2.	470K	1M	320K
3.	1M	1M	500K
4.	10K	4.7K	3.2 K
5.	1M	100K	90 K
6.	56K	1K	982 
7.	33K	22K	13.2K
8.	22K	33K	13.2K (same as above)
9.	1M	1K	1K *

* The larger 1M is ignored. The calculated R_T would be .9999K or 1K.

PARALLEL RESISTORS

3. Calculate the total equivalent Resistance for the following Parallel Resistors:

	PARALLEL RESISTORS			TOTAL RESISTANCE
	R1	R2	R3	R _T
1.	10K	2.2K	4.7K	1.3K
2.	10K	10K	10K	3.3K
3.	1K	470K	1M	1K
4.	3.3K	3.3K	3.3K	1K
5.	15K	56K	22K	7.7K

← rounded
off 3.33K

← rounded
off .997K

SERIES-PARALLEL CIRCUIT

The rules for calculating equivalent resistance for Series and Parallel Resistors are used to calculate expected current. Test results are compared to predicted values.

2. For the resistance of 400K the corresponding current from the graph in Experiment #2 is:

$$I \left(\begin{array}{c} \text{GRAPH} \\ 400K \end{array} \right) = 26 \quad \mu a$$

Using Ohm's Law, the calculation of current in the 400K resistor is:

$$I = +V2(2.5) \mu a = 10 \times 2.5 = 25.0 \quad (+V2 \text{ from Experiment \#1 paragraph 11 is 10 volts.})$$

$$I \left(\begin{array}{c} \text{OHMS} \\ \text{LAW} \end{array} \right) = 25 \quad \mu a$$

3. Current measured in this experiment:

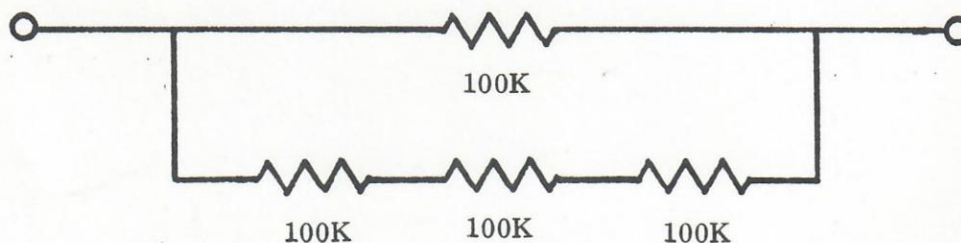
$$I \text{ (MEASURED)} = 25 \quad \mu a$$

The measured current above is close to the calculated current using the graph and exactly the current calculated using Ohm's Law.

EXERCISES:

1. Calculate the equivalent resistance for:

A.

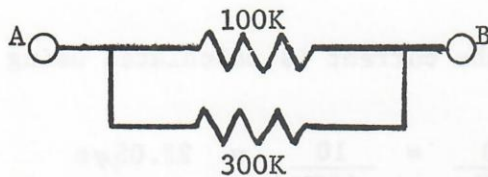


The Total Series Resistance R_s of the lower branch of the circuit is:

$$R_s = 100K + 100K + 100K = 300K$$

SERIES-PARALLEL CIRCUIT

We can now redraw the circuit to look like this:



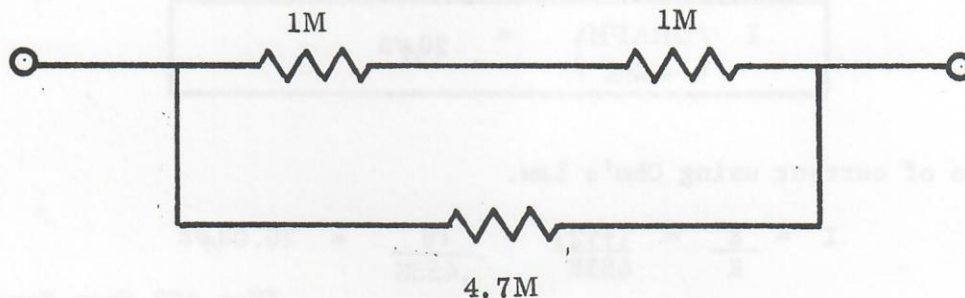
R_T = Resistance from A to B

The total resistance of this circuit is found by combining the 100K and 300K resistors in parallel.

$$R_T = \frac{(100K)(300K)}{100K + 300K} = \frac{30,000K^2}{400K} = \frac{30,000K}{400} = \frac{300K}{4} = 75K$$

$$R_T = 75K$$

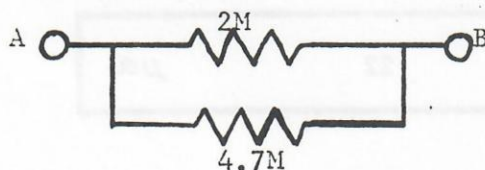
B.



The total Series Resistance R_s of the two 1M resistors in the upper branch is:

$$R_s = 1M + 1M = 2M$$

The circuit can now be redrawn as shown below:



The total resistance between A and B is the parallel combination of the 1M and 4.7M resistors.

$$R_T = \frac{2M(4.7M)}{2M + 4.7M} = \frac{9.4(M)M}{6.7M} = \frac{9.4M}{6.7} = 1.4M$$

$$R_T = 1.4M$$

PARALLEL-SERIES CIRCUIT

The Equivalent Resistance is calculated to predict expected circuit current.

CALCULATION

For a voltage (+V2) of 9.5 volts, the current is calculated using OHM's Law as follows:

$$I = \frac{E}{R} = \frac{(+V2)}{453K} = \frac{(10)}{453K} = \frac{10}{.453M} = 22.08 \mu a$$

$$I \text{ (AT 9.5 volts)} = 21 \mu a$$

CALCULATE THE EXPECTED CURRENT

2. Current from graph in experiment #2 at a resistance of 450K

$$I \text{ (GRAPH)} = 20 \mu a$$

Calculation of current using Ohm's Law.

$$I = \frac{E}{R} = \frac{(+V2)}{453K} = \frac{10}{.453M} = 20.08 \mu a$$

(Use +V2 from Experiment No. 1)

$$I \text{ (Ohms Law)} = 20.08 \mu a$$

Measured current from actual circuit.

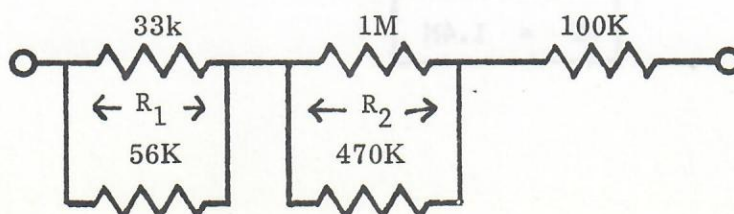
$$I \text{ (MEASUREMENT)} = 22 \mu a$$

4. Calculated and measured currents are close in value. The % difference is $\frac{22-20}{22} \times 100\%$

EXERCISES:

9%

1. Calculate the equivalent resistance.



$$R_T = 440K$$

PARALLEL-SERIES CIRCUIT

R1 = Parallel combination of 33K and 56K resistors.

$$R1 = \frac{(33)K(56)K}{(33 + 56)K} = \frac{1848KK}{89K} = \frac{1858K}{89} = 20.76K$$

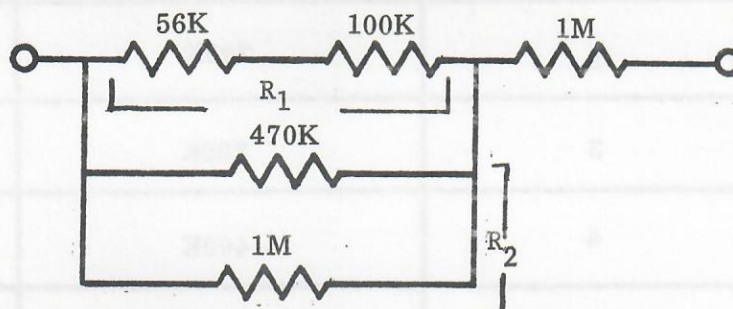
R2 = Parallel combination of 1M (1000K) and 470K resistors

$$R2 = \frac{1000K(470K)}{1000K + 470K} = \frac{470,000KK}{1470K} = \frac{470,000K}{1470} = 319.72K$$

$$RT = \text{Total circuit resistance} = R1 + R2 + 100K = 319.72K + 20.76K + 100K = 440.48K$$

$$RT = 440K$$

B.



R1 = Series combination of 56K and 100K

$$R1 = 56K + 100K = 156K$$

R2 = Parallel combination of 470K and 1M resistors

$$R2 = \frac{(470)K(1000)K}{(470 + 1000)K} = \frac{470,000KK}{1470K} = 319.72K = 320K$$

R3 = Parallel combination of 320K and 156K

$$R3 = \frac{320K(156K)}{(320 + 156)K} = \frac{49920K}{476K} = 104.8K = 105K$$

$$RT = \text{Total Resistance} = R3 + 1M = 105K + 1M = 0.105M + 1M = 1.1M$$

$$RT = 1.1M$$

VARIABLE RESISTOR

A VARIABLE RESISTOR or RHEOSTAT is adjusted and the resultant circuit current is measured and plotted on a graph.

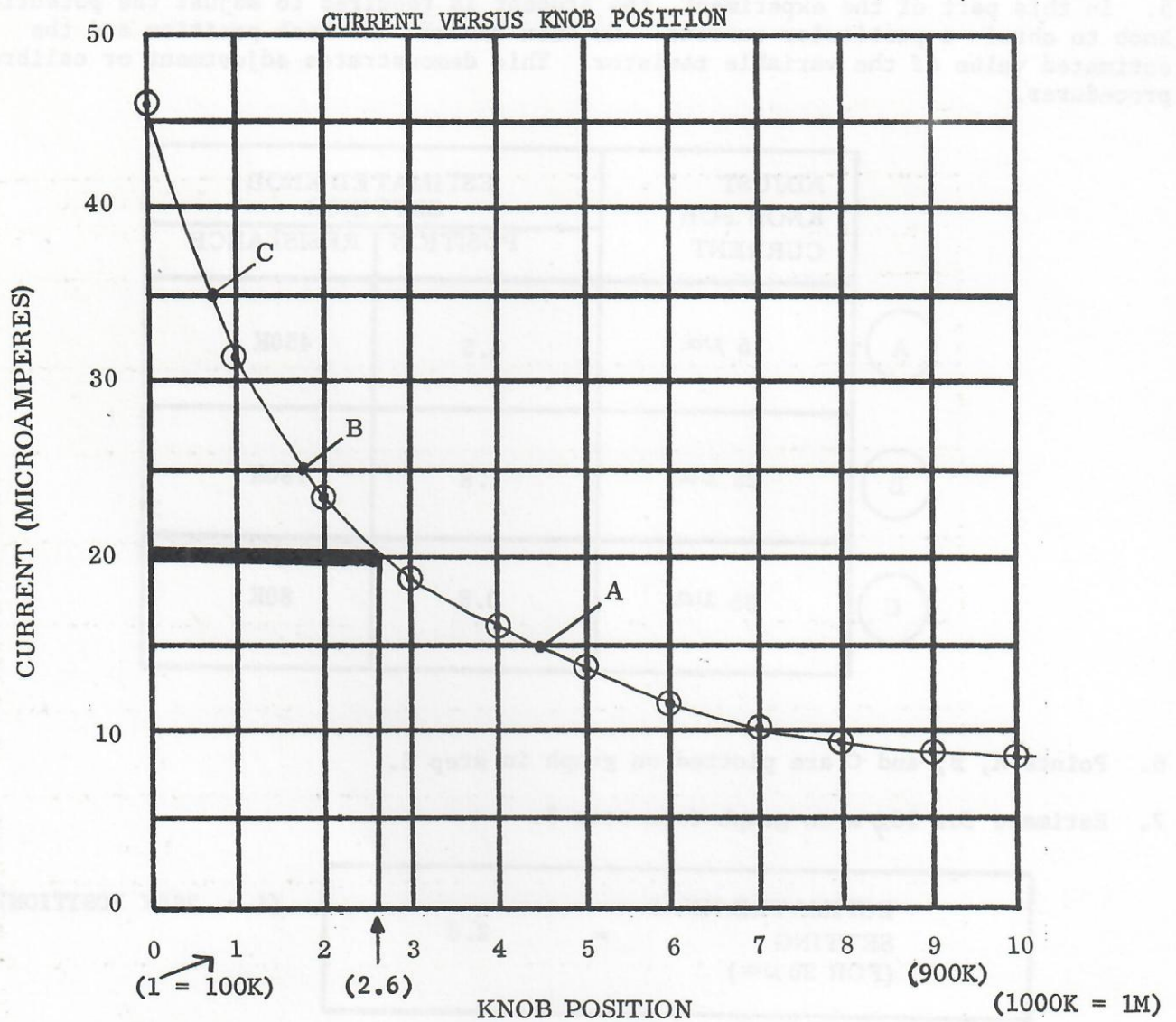
2. Variable Resistance data

KNOB SETTING	POT RESISTANCE	MEASURED CURRENT μa
0	0	46.0
1	100K	32.0
2	200K	23.5
3	300K	18.5
4	400K	16.0
5	500K	13.5
6	600K	12.0
7	700K	10.0
8	800K	9.0
9	900K	8.75
10	1000K = 1M	8.5

3. Graph of recorded data from step 2.
(Points A, B and C plotted from step 6)

(see graph on next page)

VARIABLE RESISTOR



4. Maximum and minimum obtainable currents.

I MAXIMUM	=	46 μ a
I MINIMUM	=	8.5 μ a

← The series 215K "LIMITS" the current to 46 μ a.

← The maximum resistance of 1M . results in a minimum current of 8.5 μ a.

VARIABLE RESISTOR

5. In this part of the experiment, the student is required to adjust the potentiometer knob to obtain a particular current. He then records the knob position and the estimated value of the variable resistor. This demonstrates adjustment or calibration procedures.

	ADJUST KNOB FOR CURRENT	ESTIMATED KNOB SETTINGS	
		POSITION	RESISTANCE
(A)	15 μa	4.5	450K
(B)	25 μa	1.8	180K
(C)	35 μa	0.8	80K

6. Points A, B, and C are plotted on graph in step 3.

7. Estimate for 20 μa on graph from step 3.

ESTIMATED KNOB SETTING (FOR 20 μa)	=	2.6	(i.e. 260K POSITION)
--	---	-----	----------------------

8. Adjust knob to above position and read meter.

CURRENT =	21 μa
-----------	------------

The correspondance of currents is very close.

$$\% \text{ ERROR} = \frac{21 - 20}{20} \times 100\% = \frac{1}{20} \times 100\% = 5\%$$

VOLTAGE METER

A VOLTMETER is built by using a Resistor in Series with the Microammeter. This experiment demonstrates that meter movements measure Current. A series resistor must be used with the meter movement to measure Voltage.

2.

+V1 Variable from 0 VOLTS to 9.8 VOLTS

3.

+V2 = 9.9 volts

4. Note: The meter leads must be reversed to perform this measurement.

-V2 = -10 VOLTS

QUESTIONS: (These questions assume a microammeter with zero resistance.)

1. What value series resistor would be used to construct at +100 VOLT Full-Scale VOLTMETER with the 50 μ a Meter Movement? ANSWER: 2 Megohms

$$R = \frac{E}{I} = \frac{100 \text{ volts}}{50 \mu\text{amps}} = \frac{100 \text{ Megohms}}{50} = 2 \text{ Megohms}$$

2. What value series resistor would be used to construct a +1000 VOLT Full-Scale VOLTMETER? ANSWER: 20 Megohms

$$R = \frac{E}{I} = \frac{1000 \text{ volts}}{50 \mu\text{amps}} = \frac{1000 \text{ Megohms}}{50} = 20 \text{ Megohms}$$

3. What value resistance would be required to construct a +1 VOLT Full-Scale VOLTMETER? ANSWER: 20 Kilohms

$$R = \frac{1 \text{ volt}}{50 \mu\text{amps}} = \frac{1,000,000}{50} = 20,000 = 20K \text{ ohms}$$

4. What value resistance would be required to construct a +10 VOLT Full-Scale VOLTMETER with a 1 milliamp (1000 microamp) Meter Movement? ANSWER: 10 Kilohms

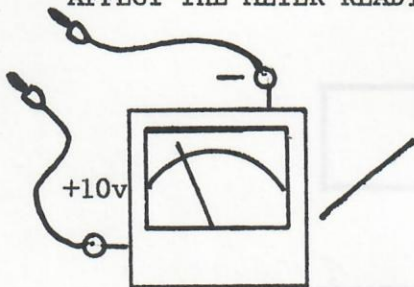
$$R = \frac{10 \text{ volts}}{1 \text{ ma}} = \frac{10K}{1} = 10K \text{ ohms}$$

KIRCHHOFF'S VOLTAGE LAW

In this experiment a series circuit with 3 resistors is tested to verify Kirchhoff's Voltage Law. This is done by measuring the supply voltage and the voltage across each of the series resistors.

Kirchhoffs Voltage Law states that the sum of the voltages across each of the series resistors is equal to the Source Voltage.

2. The meter is used on the 10 volt scale. Connection leads are used as test probes of this voltmeter to make the voltage measurement of the circuit. BE SURE THAT FINGERS DO NOT TOUCH THE LEADS OR THE SCREWS ON THE BANANA LEADS. THIS MAY AFFECT THE METER READINGS.



USE METER ON ED-LAB 650

Note: The supply voltage will vary between trainers.

SOURCE VOLTAGE
or
SUPPLY VOLTAGE

$V_S = 9.8$ VOLTS

DATA

RESISTANCE	VOLTAGE
1K	$V_1 = 1.5$
2.2K	$V_2 = 3.3$
3.3K	$V_3 = 4.9$
VOLTAGE SUM	$V_T = 9.7$

← ADD THE VOLTAGES

3. The voltages V_1 , V_2 , V_3 are added together. This sum voltage will equal the source voltage within allowable errors of measurement. The sum V_T should be a little less than the source V_S because of some meter "loading" which is discussed later.

$V_S = 9.8$ volts

$V_T = 9.7$ volts

The voltages are close. $\% \text{ Error} = \frac{9.8 - 9.7}{9.8} \times 100\% = \frac{0.1}{9.8} \times 100\% = 1\%$

We have verified Kirchhoff's Voltage Law

EXERCISES:

1. Calculate the Current in each resistor using OHM's Law.

KIRCHHOFF'S VOLTAGE LAW

The current in each resistor for the test circuit is calculated using OHM's LAW. Since these resistors are all in series, the current in each resistor will be the same.

RESISTANCE	CALCULATE CURRENT
1K	$I_1 = \frac{V_1}{1K} = \frac{1.3}{1} = 1.5 \text{ milliamperes}$
2.2K	$I_2 = \frac{V_2}{2.2K} = \frac{3.3}{2.2} = 1.5 \text{ milliamperes}$
3.3K	$I_3 = \frac{V_3}{3.3K} = \frac{4.9}{3.3} = 1.27 \text{ milliamperes}$

2. The calculated currents flowing in each resistor is approximately the same. We know that it is the same current. The % Error = $\frac{1.5 - 1.48}{1.5} \times 100\% = \frac{0.02}{1.5} \times 100\% = 1.3\%$
3. Calculate the expected current (IE) using OHM's LAW.

$$R_T = 1K + 2.2K + 3.3K = 6.5K$$

$$\begin{array}{l} \text{EXPECTED} \\ \text{CURRENT} \end{array} \quad I_E = \frac{V_S}{R_T} = \frac{9.8}{6.5K} = 1.50 \text{ milliamperes} \quad (V_S \text{ is measured supply voltage})$$

$$I_E = 1.5 \text{ milliamps}$$

4. The above expected current agrees closely with the measured currents I₁, I₂, and I₃.

The calculated $I_E = 1.50 \text{ milliamps}$

The current calculated in exercise 1 which is furthest away from 1.26 milliamps is the current for I₃ = 1.48

$$\% \text{ Error} = \frac{1.5 - 1.48}{1.5} \times 100 = \frac{0.02}{1.5} \times 100 = 1.3\%$$

$$\% \text{ Error} = 1.3\%$$

This is the maximum error between calculated I_E and the individual resistor current calculations.

MULTI-LOOP CIRCUIT

In this experiment a circuit with multiple loops is tested and KIRCHHOFF'S VOLTAGE LAW verified for each of the loops in the circuit. The circuit for this experiment has three separate loops. Kirchhoff's Voltage Law applies to each of these loops.

2. Using the 10 volt meter scale, the voltage source is measured.

$$V_S = 9.5 \text{ VOLTS}$$

3 & 4.

LOOP #1

ENTER DATA
↓

RESISTANCE	VOLTS	MEASURED VOLTAGE
1K	V_1	2.6
2.2K	V_2	2.6
3.3K	V_3	4.0
SUM		9.2

The sum is 9.2 volts. V_S is 9.5 volts. Yes, Kirchhoff's Voltage Law is verified.

$$\% \text{ Error} = \frac{9.5 - 9.2}{9.5} \times 100\% = \frac{0.3}{9.5} \times 100\% = 3.0\%$$

5 & 6.

LOOP #2

RESISTANCE	VOLTS	MEASURED VOLTAGE
1K	V_1	2.6
4.7K	V_4	6.7
SUM		9.3

Yes, Kirchhoff's Voltage Law is verified in Loop #2.

$$\% \text{ Error} = \frac{9.5 - 9.3}{9.5} \times 100\% = \frac{0.2}{9.5} \times 100\% = 2.0\%$$

MULTI-LOOP CIRCUIT

7 & 8.

LOOP #3

RESISTANCE	VOLT	MEASURED VOLTAGE
2.2K	V ₂	+ 2.6
3.3K	V ₃	+ 4.0
4.7K	V ₄	- 6.7
SUM		- 0.1

note minus sign

Yes, Kirchoff's Voltage Law is verified. The sum of voltages around a loop measures nearly zero.

EXERCISES:

1. Calculate the current in the 1K Resistor using OHM's LAW and based on the measurement of the Voltage, V₁.

$$I_1 = \frac{V_1}{1K} = \frac{2.6 \text{ volts}}{1K} = 2.6 \text{ milliamperes}$$

$$I_1 = 2.6 \text{ milliamperes}$$

2. Calculate I_C based on your measurement of V_S and the circuit resistance.

$$I_C = \frac{V_S}{3.5K} = \frac{(9.5)}{3.5K} \quad I_C = 2.7 \text{ milliamperes}$$

3. The calculated current I_C and the measured current I₁ are nearly equal. They should be the same and the calculations should be close.

4. State Kirchoff's Voltage Law?

The sum of voltages around a series circuit is equal to the applied source voltage... or...The sum of the voltages around a closed loop is equal to zero.

5. Total Resistance = R_T = 4.7K + 10K + 3.3K = 18.0 K

$$I = \frac{E}{R} = \frac{V_S}{R_T} = \frac{18 \text{ volts}}{18K} = 1 \text{ milliampere}$$

$$V = R \times I$$

MULTI-LOOP CIRCUIT

$$V1 = (4.7K)(I) = (4.7K)(1 \text{ milliamp}) = 4.7 \text{ volts}$$

$$V2 = (10K)(I) = (10K)(1 \text{ milliamp}) = 10 \text{ volts}$$

$$V3 = (3.3K)(I) = (3.3K)(1 \text{ milliamp}) = 3.3 \text{ volts}$$

$$V1 + V2 + V3 = 4.7K + 10 + 3.3 = 18 \text{ volts}$$

KIRCHHOFF'S LAW IS VERIFIED SINCE $V_S = 18 \text{ volts}$
and $V_S = V1 + V2 + V3$

6. Repeat the above exercise using a Source or Supply Voltage of 36 VOLTS.

$$R_T = 4.7K + 10K + 3.3K = 18K$$

$$I = \frac{V_S}{R_T} = \frac{36}{18K} = 2 \text{ milliamps}$$

$$V1 = (4.7K)(2 \text{ ma}) = 9.4 \text{ volts}$$

$$V2 = (10K)(2 \text{ ma}) = 20 \text{ volts}$$

$$V3 = (3.3K)(2 \text{ ma}) = 6.6 \text{ volts}$$

$$V1 + V2 + V3 = 9.4 + 20 + 6.6 = 36 \text{ volts}$$

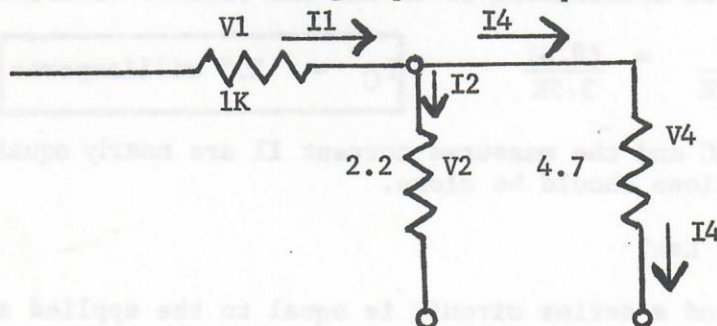
KIRCHHOFF'S VOLTAGE LAW IS VERIFIED BECAUSE:
 $V_S = V1 + V2 + V3$

INSTRUCTORS NOTES:

You can also verify Kirchhoff's Current Law described later on in Experiment 18.

The Sum of Currents entering a point is equal to the sum of currents leaving the point.

or... The sum of Current entering a point is equal to zero,



$$I1 = \frac{V1}{1K} = \frac{2.6}{1} = 2.6 \text{ ma} \quad I2 = \frac{V2}{2.2K} = \frac{2.6}{2.2} = 1.2 \text{ ma}$$

$$I4 = \frac{V4}{4.7K} = \frac{6.7}{4.7} = 1.4 \text{ ma}$$

$I1 = 2.6 \text{ ma}$ should be equal to $I2 + I4 = 1.2 + 1.4 = 2.6 \text{ ma}$ KIRCHHOFF'S CURRENT LAW is verified.

VOLTAGE DIVIDER

The VOLTAGE DIVIDER circuit is common in many electronics circuits. A simple two resistor voltage divider is examined. Experiments #10, 11, 12, 13, 14 and 15 are concerned with Voltage Dividers.

2.

$$V_s = 9.6 \text{ volts}$$

3. Calculation of expected output voltage, V_e across the 2.2K Resistor.

$$V_{out} = (V_s)(0.68)$$

$$V_{out} = (9.6)(0.68) = 6.53 \text{ (round-off answer)}$$

$$V_e = 6.53 \text{ VOLTS}$$

CALCULATION

4. Measurement of V_{out} across the 2.2K Resistor.

$$V_{out} = 6.4 \text{ VOLTS}$$

MEASUREMENT

5. The expected or calculated $V_e = 6.5$ volts and the measured $V_{out} = 6.4$ volts are close. Our calculations and measurements agree.

6. Calculate the expected Voltage Divider outputs in Column B below:

7. Measure the output voltages and enter data in Column C below:

(data tables for 6, and 7 on following page)

VOLTAGE DIVIDER

use + V2 as Vs measured in paragraph 2 (Vs = +V2 = 9.6)

(A)		(B) CALCULATE	(C) MEASURE
R1	R2	$V_e = (+V2) \frac{R2}{(R1 + R2)}$	V _{out}
1K	2.2K	$V_e = (+V2) \frac{(2.2)}{3.2}$ $= (9.6)(.68)$ $V_e = 6.5$	6.4
1K	1K	$V_e = (+V2) \frac{1}{2} = \frac{(9.6)}{2}$ $V_e = 4.8$	4.6
1K	3.3K	$V_e = (+V2) \frac{3.3}{4.3} = \frac{9.6(3.3)}{4.3}$ $V_e = 7.38$	7.30
1K	100	$V_e = (+V2) \frac{100}{1100} = \frac{9.6}{11}$ $V_e = 0.87$	0.85
3.3K	1K	$V_e = (+V2) \frac{1}{4.3} = \frac{9.6}{4.3}$ $V_e = 2.2$	2.1

8. The calculated or expected values (Column B) agrees with the measured values (Column C).

EXERCISES:

1. The supply voltage is 8 volts. The output voltage is 3.3 volts. Resistor R2 is 3.3K. Can you guess the value of the series Resistor R1?

The voltage across R1 is (Vs - Vout) = (8 - 3.3) = 4.7 volts

if 3.3 volts is across R2 of 3.3K then 4.7 volts is across R1 of 4.7K

$$R1 = 4.7K$$

2. Calculate the value of Resistor R1. The current, I in R2 is given by:

$$I = \frac{V_{out}}{R2} = \frac{3.3V}{3.3K} = 1ma$$

The same current flows in R1.

The voltage across R1 is equal to (Vs - Vout) = (8 - 3.3) = 4.7V

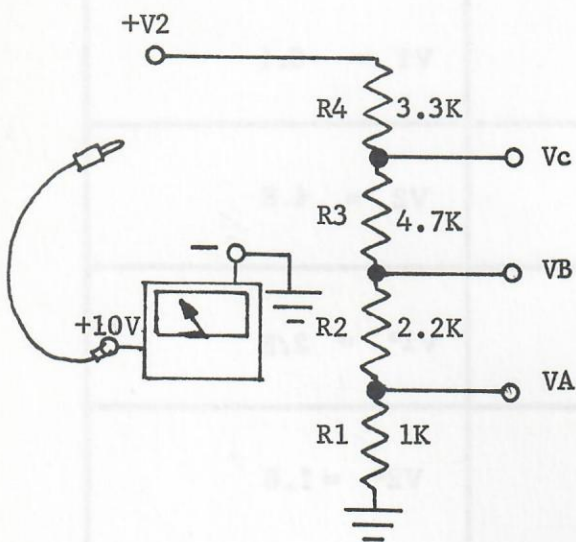
VOLTAGE DIVIDER

The Resistance R1 is given by:

$$R1 = \frac{V}{I} = \frac{4.7}{1} = \frac{4.7}{1\text{ma}} = 4.7\text{K}$$

$$R1 = 4.7\text{K}$$

INSTRUCTORS NOTE:



Voltage Dividers can consist of a number of series resistors with many outputs as shown in the accompanying diagram. There are a number of output voltages designated as Vc, VB, and VA. Wire the circuit. Measure +V2. Calculate the expected voltages EV_A , EV_B , EV_C . Measure the output voltages: VA, VB, VC. Compare the measured voltages.

CIRCUIT SWITCHES

Two single pole, double throw SWITCHES are used to change the circuit resistance and voltage divider output voltages. This experiment demonstrates the use of switches and voltage dividers with more than one output as shown in the previous experiment.

2. Measurement of voltages with switches in various positions.

SWITCH A	SWITCH B	OUTPUT VOLTAGE
UP (HIGH VOLT) RANGE	UP	V1 = 8.1
	DOWN	V2 = 4.8
DOWN (LOW VOLT) RANGE	UP	V1* = 2.5
	DOWN	V2* = 1.6

3. Which Switch is used to change the circuit Currents and Voltages?
ANSWER: SWITCH A.
4. Which Switch is used to change the point at which the Voltage is measured?
ANSWER: SWITCH B.
5. Use the Meter +10V input LEAD, and measure the Supply Voltage (Vs) at (+V2).

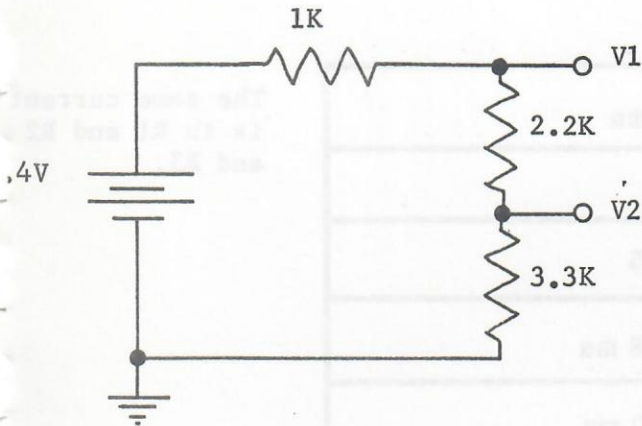
$$V_s = 9.8 \text{ volts}$$

EXERCISES:

1. Use the measurement of Vs above and the Voltage Divider equations to calculate the expected or theoretical voltages V1 and V2 for both circuits.

CIRCUIT SWITCHES

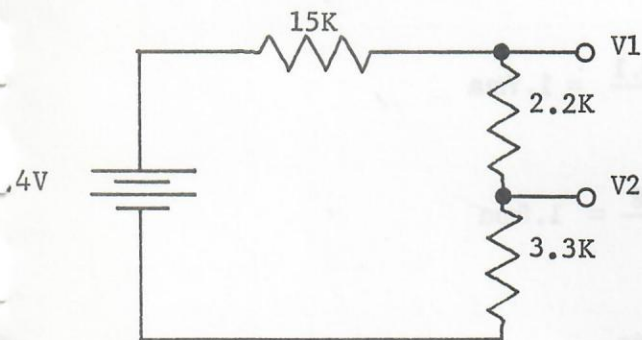
SWITCH A UP



$$V_1 = \frac{(2.2K + 3.3K)9.8V}{2.2K + 3.3K + 1} = \frac{5.5(9.8V)}{6.5} = 8.3 \text{ Volts}$$

$$V_2 = \frac{(3.3K)9.8}{1K + 2.2K + 3.3K} = \frac{(3.3)(9.8)}{6.5} = 4.97 \text{ Volts}$$

SWITCH A DOWN



$$V_1^* = \frac{(2.2K + 3.3K)9.8}{2.2K + 3.3K + 15K} = \frac{(5.5)(9.8)}{20.5} = 2.6 \text{ Volts}$$

$$V_2^* = \frac{(3.3K)(9.8)}{15K + 2.2K + 3.3K} = \frac{(3.3)(9.8)}{20.5} = 1.6 \text{ Volts}$$

CALCULATIONS FROM ABOVE:

CLOSE
COMPARISON WITH
MEASUREMENTS
BELOW:

SWITCH A UP	$V_1 = 8.3$
	$V_2 = 4.97$
SWITCH A DOWN	$V_1^* = 2.6$
	$V_2^* = 1.6$

8.1

4.8

2.5

1.6

(from previous page)

2. Use the measured Voltages in Paragraph 2 of the experiment to calculate the currents, I_1 , I_2 , and I_3 in Resistors R_1 , R_2 and R_3 Switch A UP and DOWN.

(Table on next page)

CIRCUIT SWITCHES

SWITCH A UP	$I_1 = 1.7\text{ma}$
	$I_2 = 1.5$
	$I_3 = 1.45$
SWITCH A DOWN	$I_1^* = 0.48\text{ ma}$
	$I_2^* = 0.40\text{ ma}$
	$I_3^* = 0.48\text{ ma}$

The same current
is in R1 and R2
and R3.

$$I_1 = \frac{V_s - V_1}{1K} = \frac{9.8 - 8.1}{1K} = 1.7\text{ma}$$

$$I_2 = \frac{V_1 - V_2}{2.2K} = \frac{8.1 - 4.8}{2.2K} = 1.5\text{ma}$$

$$I_3 = \frac{V_2}{3.3K} = \frac{4.8}{3.3K} = 1.45\text{ma}$$

$$I_1^* = \frac{V_s - V_1^*}{15K} = \frac{9.8 - 2.5}{15K} = 0.98\text{ma}$$

$$I_2^* = \frac{V_1^* - V_2^*}{2.2K} = \frac{2.5 - 1.6}{2.2K} = 0.40\text{ma}$$

$$I_3^* = \frac{V_2^*}{3.3K} = \frac{1.6}{3.3K} = 0.48\text{ma}$$

POTENTIOMETER

The 10K ohm POTENTIOMETER and 1 megohm potentiometer are rotated and used as variable voltage dividers. The effect of "loading" by the meter is observed when using the 1M POT.

2. Output voltage versus pot position data table.

DATA ENTERED ↘

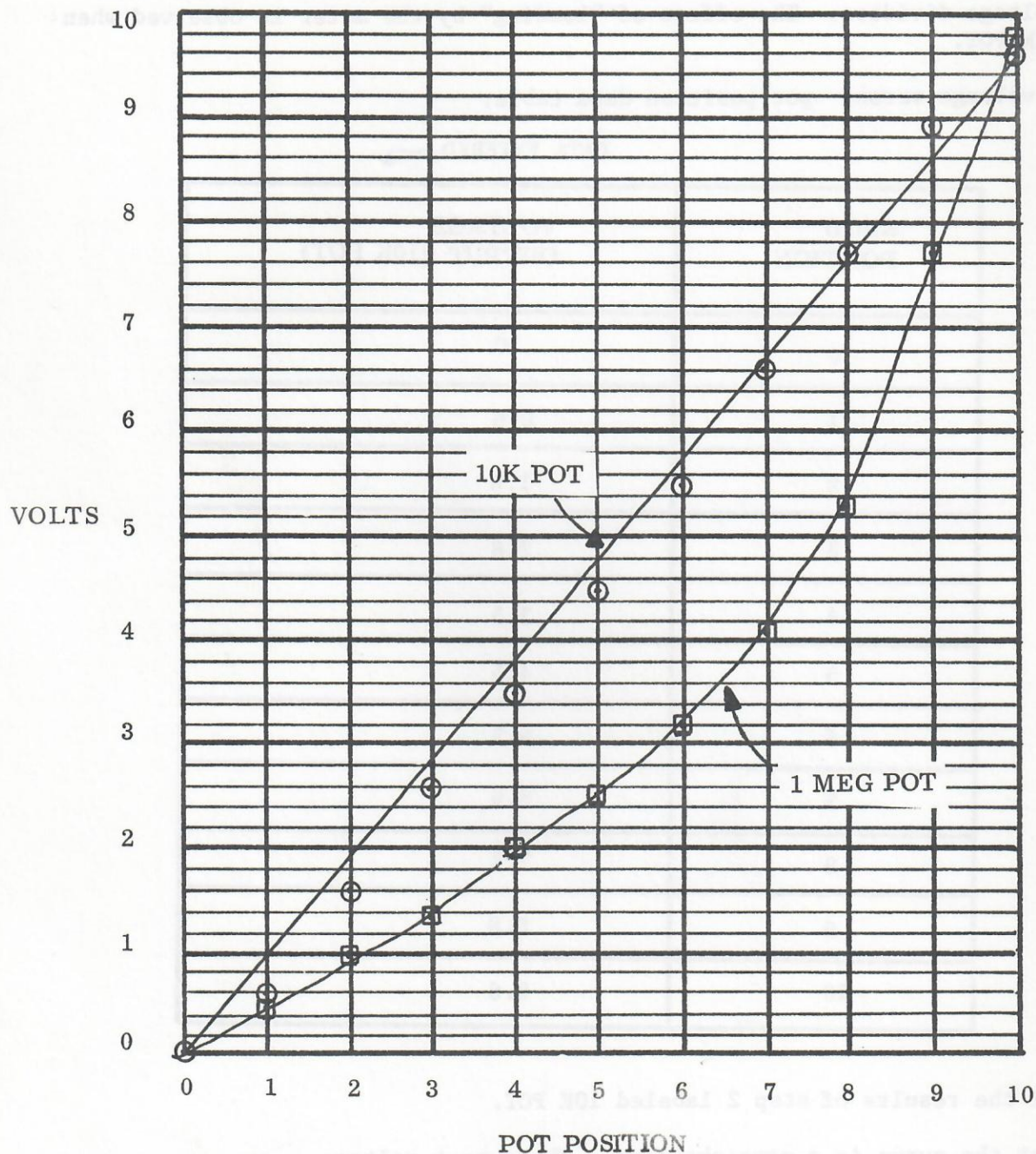
KNOB POSITION	VOLTAGE OUTPUT (10K POT)
0	0
1	0.6
2	1.6
3	2.6
4	3.5
5	4.5
6	5.5
7	6.6
8	7.7
9	8.9
10	9.6

3. Graph of the results of step 2 labeled 10K POT.

Note that the curve is a straight line. The output voltage increase linearly with increased POT position.

(Graph on next page)

POTENTIOMETER



- The 1 Meg POT is substituted for the 10K POT and the output voltage versus POT Position is recorded.

INSTRUCTORS NOTE:

The meter is used on the 10 volt scale. On this scale the meter has 200K ohms impedance. Therefore, the meter presents a 200K ohm load to the potentiometer and the voltage will not be the normal unloaded voltages. As the resistance

POTENTIOMETER

of the POT from the wiper to ground is increased, the loading effect of the meter is more noticable. This is because the resistance from the wiper to ground is actually the parallel combination of the POT resistance and the meter resistance.

KNOB POSITION	OUTPUT VOLTAGE (1M POT)
0	0
1	0.4
2	1.0
3	1.4
4	2.0
5	2.5
6	3.2
7	4.1
8	5.3
9	7.7
10	9.8

Note:
(correction,
should be
1M POT)

5. The results from step 4 is drawn on the Graph and is labeled "1M POT." The curvature of this plot should be clearly seen in contrast with the plot obtained using the 10K POT.

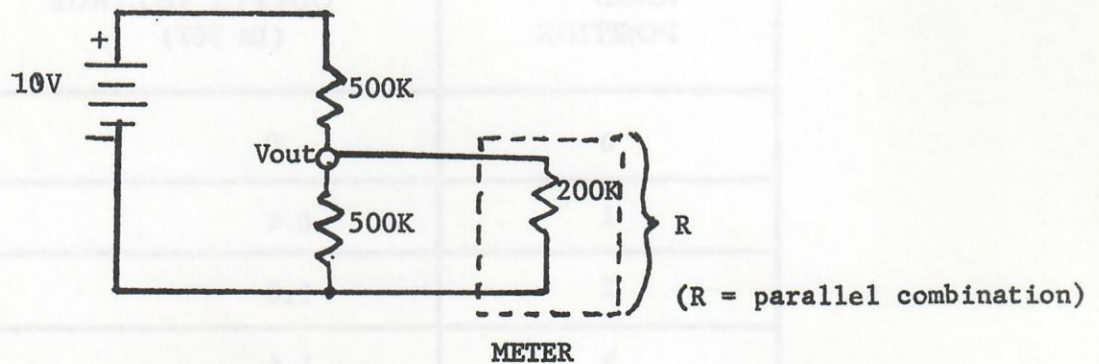
The Curve from the 1M POT is lower than the curve from the 10K POT. This is because the meter Loads the circuit when the 1M POT is used.

6. The curve using the 1M POT is not a straight line (non-linear). The meter does not load the 10K POT because 200 kilohms is much larger than the 10K POT resistance. The meter does load the 1M POT because 200K is lower than 1M and with two parallel resistors, the lower resistor has a large effect.

POTENTIOMETER

EXERCISES:

1. Consider a Power Supply Voltage of $E = 10$ VOLTS connected across a 1 Megohm Potentiometer. The Potentiometer is set in MID Position (with 500K resistance at each side of the wiper.) The output voltage of this voltage divider is 5 VOLTS. What voltage will be read on a METER connected to the output? (The meter has 200K resistance.)



$$R = \frac{(500)(200)K}{500 + 200} = \frac{100,000K}{700} = \frac{1000K}{7} = 142.8K$$

$$V_{out} = \frac{R(10)}{R + 500K} = \frac{(142.8)(10)}{142.8 + 500} = \frac{1428}{642.8} = 2.2 \text{ volts}$$

$V_{out} = 2.2 \text{ volts}$

HIGH RESISTANCE VOLTAGE DIVIDER

This experiment demonstrates the **LOADING** effect of the meter resistance on a high resistance voltage divider circuit. The resistance of the meter affects the voltage divider circuit and gives an improper reading for the voltage divider.

2. Measurement of the Power Supply Voltage (+V2)

$$+V2 = 9.8 \text{ Volts}$$

also called (Vs)

3. Calculating of Output Voltage (theoretical or expected).

$$\begin{aligned} V_e &= (.7)(+V2) \\ &= (.7)(9.8) \quad (\text{SUBSTITUTE } +V2) \end{aligned}$$

EXPECTED OUTPUT

$$V_e = 6.86 \text{ Volts}$$

EXPECTED

4. Measurement of Output Voltage (across the 470K Resistor)

$$V_{out} = 3.95 \text{ Volts}$$

MEASURED

5. How does your above measured output voltage (Vout) compare with the calculated or expected output voltage (Ve) in Paragraph 3 above?

The measured Vout is close to half of the expected or calculated Voltage. There is definitely a problem. Probably loading as seen in the potentiometer experiment.

6. Output Voltage, V:

$$V = V_s \frac{140}{340} = 9.8 \frac{(140)}{340} = 4.0$$

$$V = 4.0 \text{ Volts}$$

This above calculation of 4.0 Voltage is identical to the measured value Vout of 3.95 volts.

HIGH RESISTANCE VOLTAGE DIVIDER

INSTRUCTORS NOTE:

1. It is possible to read the proper voltage by a "balancing" method as shown in the POTENTIOMETRIC VOLTmeter demonstrated next, in Experiment #14 It is also possible to obtain a correct reading using an input TRANSISTOR VOLTmeter demonstrated in Experiment #15.

POTENTIOMETRIC VOLTMETER

A "BALANCING" method is used to measure voltage without loading the circuit.

3. Measurement of POT Voltage after Balance Adjustment.

$$V_x = 6.8 \text{ volts}$$

4. Calculation of unloaded voltage from experiment 13, step 3.

CALCULATION
FROM BEFORE

$$V_e = V_s \frac{470}{(470 + 100K + 100K)} = V_s \frac{470}{670} = .7 V_s$$

From Experiment No. 13

CALCULATED
EXPECTED VOLTAGE

$$V_c = 6.86 \text{ volts}$$

5. The Balance Measurement resulted in a reading of $V_x = 6.8$ Volts. The calculated or Expected Voltage from Experiment #13 is $V_c = 6.86$ Volts. They are both very close. You may want to repeat the measurement of V_s in Experiment #13 and calculate V_c again for more accurate results.

QUESTIONS:

1. What do you think about this BALANCING method?

This balancing method permits accurate measurement of voltages from High Impedance sources using Low Impedance measuring devices by balancing out any output current.

2. What is the output voltage if the 470K resistor was 56K?

You have to use the Equation from Experiment #13, step 6; where:

$$R_T = 56K$$

$$V_{out} = V_s \frac{R_T}{R_T + 100K + 100K} = V_s \frac{56K}{256K}$$

$$V_{out} = (V_s)(.219)$$

Use V_s (or $+V_2$) from Experiment #13, step 2

$$+V_2 = 9.8 \text{ volts}$$

$$V_{out} = (9.8)(.219) = 2.15$$

$$V_{out} = 2.15 \text{ volts}$$

TRANSISTOR VOLTMETER

A TRANSISTOR is used in the input of the +10V meter to provide a high input resistance to measure voltages in high resistance circuits.

2. Supply Voltage Measurement

When Switch A is UP the meter is connected to measure the supply voltage.

$$V_s = 9.6 \text{ volts}$$

3. Voltage Divider Output Voltage Measurement

With Switch A DOWN the Meter is connected to read Output of the Voltage Divider.

$$V_{out} = 6.7 \text{ Volts}$$

4. Calculation of the expected Output Voltage.

$$V_e = V_s \frac{470K}{(200K + 470K)} = 0.7 V_s$$

Using the V_s measured in Step 2 of this experiment, the expected output:

$$V_e = 0.7 V_s = 0.70 (9.6)$$

$$V_e = 6.72$$

5. How does the measured V_{out} compare with your calculation for V_e ? Does the TRANSISTOR VOLTMETER Load the High Resistance Voltage Divider Circuit?

The voltages differ by only 0.02 Volts. Both would be "rounded-off" to 6.7 volts.

Note that the transistor voltmeter reading is 6.7 volts and the Potentiometric reading is 6.8 volts. There is no loading using these methods.

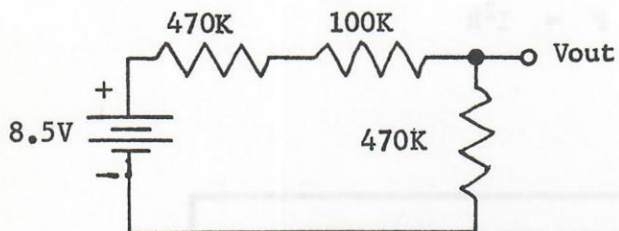
QUESTIONS:

1. What does the transistor do in this circuit?

The transistor causes the input resistance of this voltmeter circuit to be very high so it does not cause any loading. Note that the transistor is operating in the common collector amplifier mode.

TRANSISTOR VOLTMETER

2. What would be the output voltage if one of the 100K resistors was 470K?



$$V_{out} = \frac{9.6 (470)}{470 + 470 + 100}$$

$$= \frac{(9.6)(470)}{1040} = 4.34$$

$V_{out} = 4.34 \text{ volts}$

CIRCUIT POWER

The student calculates the POWER dissipated in each of three series resistors connected to a voltage source. Energy is also defined and calculated.

Power is given by:

$$P = IV \text{ or } P = \frac{V^2}{R} \text{ or } P = I^2R$$

2. Measurement of the Circuit Voltages

VOLTAGE	MEASURED VOLTAGE
V_s	9.8 volts
V_1	1.4 volts
V_2	3.1 volts
V_3	4.7 volts

3. Calculation of Current using the measured value of V_1 across the 1K resistor

$$I = \frac{V_1}{1K} = \frac{1.4}{1K} = 1.4 \text{ milliamps}$$

$I = 1.4 \text{ ma.}$

4. Calculation of the Power in each resistor.

(Table on next page)

CIRCUIT POWER

	(A)	(B)	(C)
POWER	$P = IV$	$P = I^2 R$	$P = V^2 / R$
P 1	$P_1 = IV_1 = (1.4 \times 10^{-3})(1.4)$ 1.96mw	$P_1 = I^2 \times 1K = (1.4 \times 10^{-3})^2$ $\times (10^3) = 1.96mw$	$P_1 = \frac{V_1^2}{1K} = \frac{(1.4)^2}{1K} =$ 1.96mw
P 2	$P_2 = IV_2 = (1.4 \times 10^{-3})$ $\times (3.1) = 4.3mw$	$P_2 = I^2 \times 2.2K =$ $(1.4 \times 10^{-3})^2$ $\times 2.2K = 4.3mw$	$P_2 = \frac{V_2^2}{2.2K} = \frac{(3.1)^2}{2.2K} =$ 4.3mw
P 3	$P_3 = I V_3 = (1.4 \times 10^{-3}) \times$ $(4.7) = 6.58mw$	$P_3 = I^2 \times 3.3K (1.4 \times 10^{-3})^2$ $\times 3.3K = 6.48mw$	$P_3 = \frac{V_3^2}{3.3K} = \frac{(4.7)^2}{3.3K}$ 6.69mw
SOURCE P _S	$P_S = IV_S = (1.4 \times 10^{-3}) \times$ 9.8 = 13.72mw		

5. Calculation of the total Power dissipated in all the resistors.

POWER	POWER
P ₁	1.96 mw.
P ₂	4.3 mw.
P ₃	6.58 mw.
TOTAL (P _T)	12.84 mw.

CIRCUIT POWER

6. How does the SUM compare with the source power, PS?

The measured source power is 13.72 and the total power dissipated PT is 12.84mw

The difference is 0.88 milliwatts. The total resistor power (PT) is close to the source power (PS).

7. Can you think of a "POWER-LAW" for Power in a circuit?

The Total Power dissipated in a circuit is equal to the power provided by the POWER SOURCE.

8. Energy is a measure of total power over a period of time and is given in WATT-HOURS. For power P over a time T, the total energy (E) is:

$$E = P T \quad \begin{array}{l} P \text{ is in WATTS} \\ T \text{ is in HOURS} \end{array}$$

How much energy is used in the resistors of the circuit in Figure 16-1 in 8 HOURS. (Use PT in milliwatts, with the result for E in milliwatt-hours)

$$E_R = P_T \cdot T = 13.72 \text{ mw} \times 8 \text{ hours} = 109.76 \text{ milliwatt-hours}$$

EXERCISES:

1. If a large and a small resistor are in series, which resistor dissipates more power?

Since Power = $I^2 R$ and the current is the same for both resistors, the large resistor will dissipate the larger power.

2. If a large and a small resistor are in parallel, which resistor dissipates more power?

Power = $E^2 R$ and in a parallel connection the voltage E is the same for both resistors, therefore, the smaller resistor will dissipate the most power.

3. What power is in a 1K resistor with 10 volts applied:

$$P = \frac{E^2}{R} = \frac{10^2}{1K} = \frac{100}{1000} = .1w = 100mw$$

We could use a $\frac{1}{2}$ watt (250mw) or $\frac{1}{2}$ watt (500mw) standard resistors.

4. What power is in a 100 Ohm resistor with 10 volts applied:

$$P = \frac{E^2}{R} = \frac{10^2}{100} = \frac{100}{100} = 1watt$$

We would probably use a 2 watt resistor for safety.

CIRCUIT POWER

5. What power rating is required on a small 2 ohm resistor with 10 volts applied?

$$P = \frac{E^2}{R} = \frac{10^2}{2} = \frac{100}{2} = 50w$$

NOTE: (50 watt resistors are not small. A high-power resistor is required.)

6. What value resistor has the color code RED - BLACK - RED - GOLD?

ANSWER: 2000 ohms 5%. RED = 2, BLACK = 0, RED = 00, =(2000) GOLD = 5%.

7. What value resistor has the color code BLUE - YELLOW - GREEN - SILVER?

ANSWER: 6.4 megohm 10%. BLUE = 6, YELLOW = 4, GREEN = 00000, (6,400,000) SILVER = 10%

8. What energy (in kilowatt hours) is used in a typical house which has twelve 150 watt light bulbs ON for 6 hours per day?

$$E = P_T \quad T = (150 \text{ watts}) \times 12 \text{ bulbs} \times 6 \text{ hours} = 10,800 \text{ watt hours}$$

each day = 10.8 Kilowatt hours (each day)

(In a month or 30 days, the total Energy used is $10.8 \times 30 = 324$ kilowatt hours)

= 324 KILOWATT HOURS

NOTE:

By comparison, in an electronics circuit with a 1K resistor and $V = 12$ volts, the energy used in 30 days, 6 hours per day, is:

$$E = P \cdot T = \frac{V^2}{R} T = \frac{(12)(12)}{1000} \times (30)(6) \text{ Watt Hours}$$

$$= \frac{25920}{1000} = 25.92 \text{ Watt Hours}$$

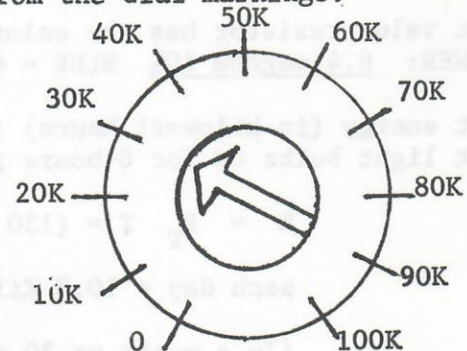
= 0.026 KILOWATT HOURS

WHEATSTONE BRIDGE

The Wheatstone BRIDGE basically consists of two voltage dividers connected in parallel. An unknown resistance is in one voltage divider. A POT is varied in the other voltage divider. When both voltage divider outputs are equal the Bridge is balanced. The position of the POT indicates the value of the unknown resistor.

2. Bridge Null Adjustment. The 10 dial markings on the 100K POT are used to estimate the resistance of each POT setting. The 100K POT is therefore, calibrated in 10K increments. When the POT is adjusted for "0" meter voltage, then the bridge is balanced and the POT resistance will be equal the resistance in the "Unknown" leg of the bridge. We can read the POT resistance from the dial markings.

$$R_u = 30K$$



3. How does the measured R_u compare with the 33K resistor used?

The estimated POT resistance is 30K, the actual "unknown" resistance is 33K. The measurement is good. You may try to estimate the position of the POT knob more accurately. Halfway between 30K and 40K is 35K.

4. The above procedure is repeated for various value of resistance inserted in the "unknown" leg.

SET R_p AT NULL

R_u UNKNOWN	KNOB POSITION (0 to 10) (at Null) (for R_p)	$R_u = R_p$ (ESTIMATED) (RESISTANCE)
10K	1	10K
15K	1.5	15K
22K	2	20K
33K	3.2	32K
56K	6	60K
100K	10	100K
480K	(Null not possible)	(Null not possible)

WHEATSTONE BRIDGE

5. How do the measured results compare with the actual resistor values?

All the values measured using the bridge are close to the actual values.

9. Table of results using the 10 to 1 bridge scaling technique.

ENTER 100K POT Knob Position at NULL (1 to 10)	Estimate R_p 0 to 100K	Calculate R_u $R_u = 10 R_p$
4.5	45K	450K

10. How does the measured R_u compare with the 470K actually used?

The resistance used is 470K. The knob position indicated 450K which is close.

QUESTIONS:

1. If R_B remained at 1K, and R_p was changed from 100K POT to the 1M POT, could you balance the bridge for an R_u of 470K?

The bridge could be balanced because the 1M POT can be adjusted to 470K.

2. What would the setting of R_p be for Null (0 to 10) for Question 1 above?

Since the 1M POT would be calibrated at 100K/division the setting to balance the 470K resistor would be 4.7. We would probably read 4.5 on the POT setting.

KIRCHHOFF'S CURRENT LAW

KIRCHHOFF'S CURRENT LAW which states that the sum of all currents entering a point is equal to the sum of currents leaving a point, is tested in this experiment.

2. Voltage Measurements

VOLTAGE	① MEASURED VOLTAGE	CALCULATED CURRENT ②
E_s	9.6 volts	
V_1	1.7 volts	$I_1 = \frac{V_1}{I_K} = 1.7 \text{ ma}$
V_2	2.2 volts	$I_2 = \frac{V_2}{2.2K} = 1.0 \text{ ma}$
		$I_3 = \frac{V_2}{3.3K} = 0.66 \text{ ma}$
V_3	5.4 volts	$I_4 = \frac{V_3}{4.7K} = 1.15 \text{ ma}$
		$I_5 = \frac{V_3}{10K} = 0.54 \text{ ma}$

3. Calculation of each current is entered in the right hand column 2 of the table in step 2.

4. Verification of Kirchhoff's Current Law.

I_2	1.0
I_3	0.66
SUM ($I_2 + I_3$)	1.66

→ SHOULD BE EQUAL TO $I_1 = 1.7$

5. Yes. The current flowing into Point A (I_1) is equal to the total current (I_2 & I_3) flowing out of Point A.

KIRCHHOFF'S CURRENT LAW

6. Verification of Kirchhoff's Current Law for Point B.

I_4	1.15 ma	SHOULD BE EQUAL TO: $I_1 = 1.7 \text{ ma}$
I_5	0.54 ma	
SUM ($I_4 + I_5$)	1.69 ma	SHOULD BE EQUAL TO: $(I_2 + I_3) = 1.66 \text{ ma}$

7. Does Kirchhoff's Current Law check for Point B?

Yes. The current into Point B is close enough to the current out of Point B to within the accuracy of the measuring devices.

8. When we assign a sign, as well as a number to the current, then we can use this definition of Kirchhoff's Current Law. THE SUM OF ALL CURRENTS ENTERING A SINGLE POINT IS ZERO.

This is done in this paragraph.

I_1	- 1.7
I_2	+ 1.0
I_3	+ 0.66
SUM	-0.04

Note: The minus sign is used to indicate conventional current flowing into POINT A. The plus sign is used to indicate conventional current flowing out of POINT A.

SHOULD BE "0".

9. Do the calculations check the theory?

Yes. The results agree with Kirchhoff's Current Law

EXERCISES:

1. Check Kirchhoff's Current Law for Point C in this Experiment.

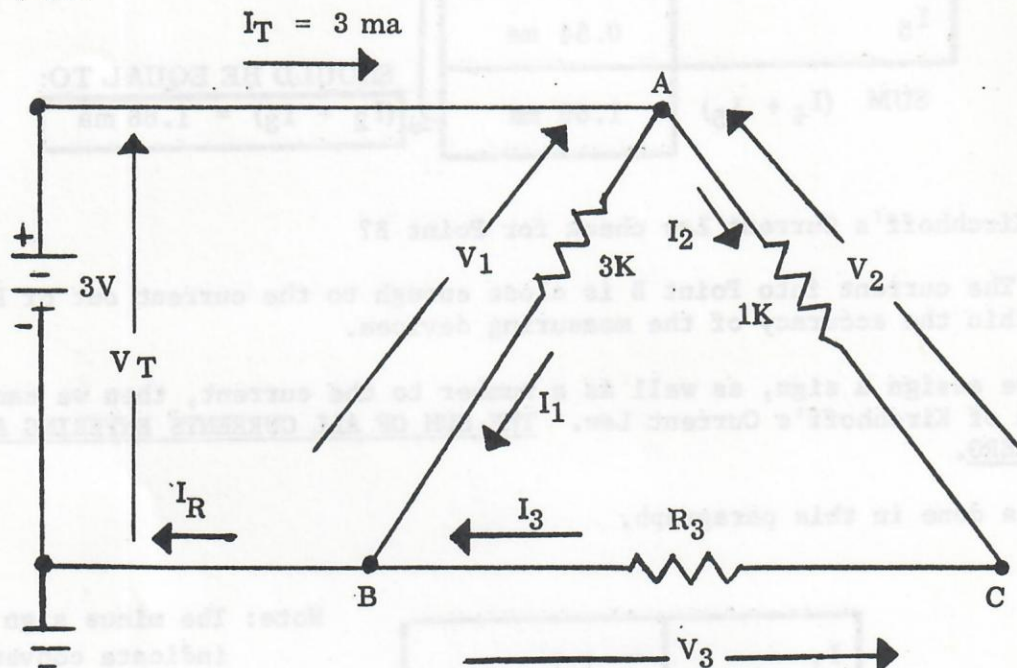
At point C the currents flowing in are I_4 and I_5 . The current flowing out is I_1 . Therefore:

$$\text{FOR POINT C } \left\{ \begin{array}{l} I_4 + I_5 = 1.15\text{ma} + 0.54\text{ma} = 1.69\text{ma} \\ I_1 = 1.7\text{ma} \end{array} \right\} \text{The results are close.}$$

$$\% \text{ Error} = \frac{1.7 - 1.69}{1.7} \times 100\% = 0.5\%$$

KIRCHHOFF'S CURRENT LAW

2. Using Kirchhoff's Current Law, Kirchhoff's Voltage Law, and Ohm's Law calculate all unknown voltages and currents and resistance in the circuit on the following page.



CALCULATE ALL UNKNOWN VALUES

V_T	3 VOLTS
I_T	3 ma.
V_1	3 volts
I_1	1 ma.
I_2	2 ma.
V_2	2 volts
I_3	2 ma.
V_3	1 volt
R_3	500 ohms
I_R	3 ma.

(same as V_T)

$$\leftarrow I_1 = \frac{V_1}{3K} = \frac{3}{3K} = 1ma$$

$$\leftarrow I_2 = I_T - I_1 = 3 - 1 = 2ma$$

$$\leftarrow V_2 = I_2 \cdot 1K = 2V$$

$$\leftarrow I_3 = I_2$$

$$\leftarrow V_3 = V_1 - V_2 = 3 - 2 = 1$$

$$\leftarrow R_3 = \frac{V_3}{I_3} = \frac{1}{2}K = 500 \text{ Ohms}$$

$$\leftarrow I_R = I_1 + I_3 \text{ or } I_T$$

METER SHUNT

A variable resistor is used in parallel or in SHUNT with the meter to divert some current from the meter. The total input current may therefore, be higher than the full scale meter current.

1. Voltage Source +V2 reading:

$$V_s = 9.8 \text{ VOLTS}$$

(Voltage at Power Supply
+V2 from previous
experiments)

2. Calculation of Current with the 33K series resistor.

$$I_1 = \frac{V_s}{33K} = \frac{9.8}{33K} = 296 \mu a$$

4. Calibration of the 1 milliamp scale of the current meter. In this case, the 1K POT is adjusted so the meter will read 2.54 on the 10 scale.

5. Switch A is placed DOWN, connecting the 22K resistor in series with the power supply, meter and shunt.

$$\text{MEASUREMENT } I_{22} = 445 \mu a$$

6. Calculation of the expected value of current with the 22K series resistor.

$$\text{CALCULATION } I_e = \frac{V_s}{22K} = 445 \mu a$$

7. The measured current of 445 μa is correct.
8. The meter can be used to read up to 1000 microamperes.

(Table can be seen on next page.)

METER SHUNT

RESISTANCE R	(A) Read Meter 1000 μ a (full scale)	(B) $I_{\mu a} = \frac{V_s}{R}$
22K	445 μ a	445 μ a
33K	300 μ a	296 μ a
15K	640 μ a	653 μ a
10K	980 μ a	980 μ a
56K	180 μ a	175 μ a
1M	10 μ a	9.8 μ a
100K	100 μ a	98 μ a
200K	50 μ a	49 μ a
470K	15 μ a	20 μ a
4.7K	over full scale	2080 μ a
3.3K	over full scale	2970 μ a

10. How do the measured and calculated values compare?

The results are all very close.

METER RESISTANCE

The RESISTANCE of the 50 μ a meter is measured.

2. Measurement of I_T and I_M .

SWITCH A DOWN	$I_T = 20 \mu a$
SWITCH A UP	$I_M = 7 \mu a$

3. Meter Resistance Calculation

$$R_m = \frac{(I_T - I_M) 1K}{I_M} = \frac{(20 - 7) 1K}{7} = \frac{13K}{7} = 1.86K$$

$$R_m = 1.86K \text{ ohms}$$

NOTE: The actual meter resistance is: 2K ohms

- 4.

$$\frac{I_T}{2} = \frac{20 \mu a}{2} = 10 \mu a$$

← 20 μ a from paragraph 2 above.

5. The various resistors are placed across the meter until the meter reads 10 μ a.

$$R_x = 2K$$

The two 1K resistors in series

6. The readings are close.

7. $R_s = 10K$

QUESTIONS:

1. Using the meter resistance R_m calculated in this experiment, calculate the shunt resistance required to have a full scale of 1ma (1 milliamperes or 1000 microamperes). Use $R_m = 2K$.

Using the equation developed in paragraph 7 of the experiment we find:

$$R_s = R_m \frac{I_m}{I_T - I_m} = \frac{2K (50 \mu a)}{(1000 \mu a - 50 \mu a)} = 105 \text{ ohms}$$

2. Calculate the shunt resistances for the following full scales; 100ma, 500ma, 1 amp.
Use $R_s = 2K$

100ma full scale - 1.05 ohms Shunt
500ma full scale - 0.2 ohms Shunt
1 amp full scale - 0.105 ohms Shunt

METER RESISTANCE

3. Calculate the shunt resistance required for a full scale reading of 10 microamps. Can you obtain a full scale reading of less than 50 microamps by using a shunt resistor? NO

Since the shunt resistor can only divert some of the current from the meter, the use of a shunt resistor cannot make the full scale reading of a meter less than the normal full scale meter reading.

$$R_s = R_m \frac{I_m}{(I_T - I_m)} = 2k \frac{10}{(10 - 50)} = \frac{20K}{-40} = -\frac{1}{2} K$$

(We would need a minus resistor)

SERIES OHMMETER

The 50 μ a meter movement is placed in series with a 100K current limiting Resistor and in parallel with a calibration 10K POT to build a SERIES OHMMETER. The series ohmmeter is a current meter with the current scale calibrated to read the series resistance in the circuit.

3. With Switch A DOWN, the OHMMETER is measuring the 100K resistance.

$$I_{(100K)} = 25.0 \mu a$$

This reading is calibrated to correspond to 100K resistance on the OHMMETER scale.

4. Various Resistors are measured using the Series Ohmmeter and the current reading is entered in Column A.

5. The Resistance values are estimated from the scale or calculated. A typical calculation is for 470K:

$$I_m = 9.4 \mu a ; R_u = 100K \frac{(50 - 9)}{9} = 100K \frac{41}{9} = 455K$$

UNKNOWN RESISTORS R_u	(A) METER READING (Scale 0 to 50) I_m MICROAMPS	(B) Calculate or Estimate $R_u = 100K \frac{(50 - I_m)}{I_m}$ (or use scale)
56K	35.0	56.25K
1M	5.0	900K
470K	9.0	455K
235K (2 of 470K in parallel)	10.0	212.5K
156K (100K+56K)	20.0	150K
33K	39.0	28.2K
22K	42.5	17.6K
15K	44.0	13.63K
10K	46.5	7.5K
3.3K	49.0	2.0K
1K	50.0	0 K

SERIES OHMMETER

6. How do the measured resistances (Column B) compare with the actual values of R_u used? The agreement is very good.

Below 22K, the readings are poorer. The errors become large when the resistors measured become much lower than the series 100K Resistor.

Additional Work:

If the student has external ohmmeters, he should measure all resistors and enter the data below. Also enter the model number of meter used, and the "scale" used.
Note: The readings of 2 different meters measuring the same resistor will be different due to calibration and accuracy of the instruments.

TYPICALLY VOM or FET VOM

TYPICALLY DIGITAL VOLTMETER

RESISTOR	METER MODEL NO.	METER MODEL NO.
4.7M		
1M		
470K		
100K		
56K		
33K		
22K		
15K		
10K		
4.7K		
3.3K		
2.2K		
1K		
100		

SHUNT OHMMETER

The SHUNT OHMMETER places the unknown resistor in parallel with the meter movement. This circuit is used to measure low resistor values, and is examined in this experiment.

3. Switch A is placed in the DOWN position so that the unknown resistor is connected across the meter movement. The current flowing in the meter is recorded.

$$I (3.3K) = 32.0 \mu a$$

4. The meter resistance measured in Experiment No. 20 is 2K.

$$R_m = 2.06K = \text{approx. } 2K$$

5. Calculation of the unknown resistor.

$$R_u = \frac{R_m (I_m)}{(50 - I_m)} = \frac{2K (32 \mu a)}{(50 \mu a - 32 \mu a)} = \frac{2K (32 \mu a)}{18 \mu a} = \frac{2(32)K}{18} = 3.5K$$

$$R_u = 3.5K$$

6. The comparison of the experimental and theoretical unknown resistance is very good.

7. Various Resistors are connected in the position of the unknown resistor and meter reading current is entered in column A.

Paragraph 8: The "Unknown" resistance is calculated and data is entered in column B.

(see table on next page)

SHUNT OHMMETER

UNKNOWN RESISTANCE R_u	METER READING (0 to 50) I_R (A)	CALCULATED R_u (B) $R_u = R_m \frac{I_R}{(50 - I_R)}$ (or use scale)
3.3K	33ua	3.8K
1K	18ua	1.125K
2.2K	27ua	2.35K
4.7K	36ua	5.1K
10K	43ua	12.28K
22K	47ua	31.3K
500 (2 of 1K in parallel)	10.5ua	532 ohm
100	3.5ua	150 ohm
200 (2 of 100 ohm in series)	5.5ua	247 ohm
470K	.50ua	∞

9. Measured values and actual values of resistance are close. Measurements of large resistance such as 470K are not possible with the Shunt Ohmmeter. The series ohmmeter circuit must be used for large resistors.

SUPERPOSITION THEOREM

This experiment demonstrates and verifies the Superposition Theorem.

2. Measurement of output voltages caused by each individual power supply.

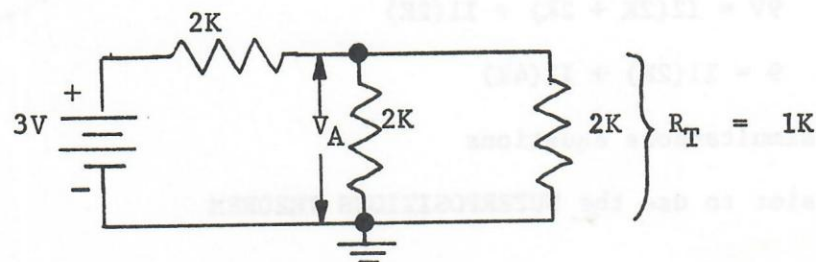
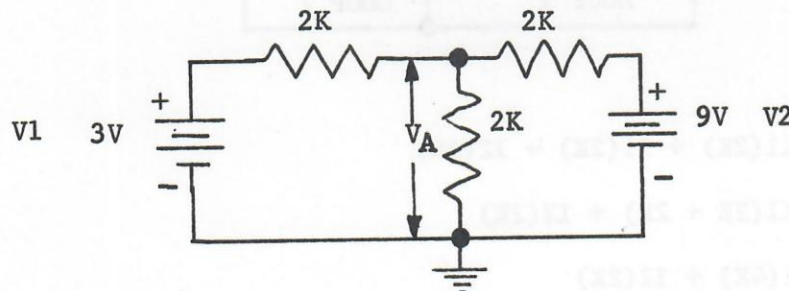
SEPARATE VOLTAGES		ENTER DATA
SWITCH A	SWITCH B	V_{out}
UP	DOWN	(From E_1) + 3.40 V
DOWN	UP	(From E_2) - 2.20 V
DOWN	DOWN	(neither) + 0
CALCULATE SUM		1.2 volts

BOTH VOLTAGES TOGETHER		ENTER DATA
SWITCH A	SWITCH B	V_{out}
UP	UP	From both ($E_1 + E_2$) 1.2Volts

3. The sum of the separate voltages and the measured voltages differ by 0.0 volts. The answer is close.

EXERCISES:

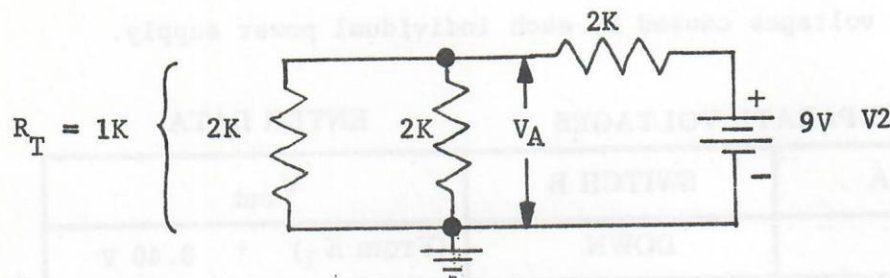
1. Using the SUPERPOSITION THEOREM, calculate the voltage V_A at point A in the circuit below:



USING
V1 ONLY
(set $V_2 = 0$)
shorted

$$V_A = \frac{3(1K)}{1K + 2K} = \frac{3}{3} = 1 \text{ volt}$$

SUPERPOSITION THEOREM



USING
V2 ONLY
(set V1 = 0)
shorted

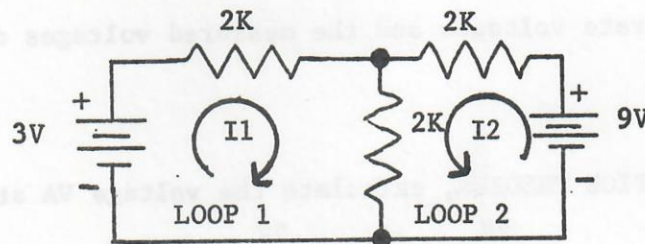
$$V_A = \frac{9(1K)}{1K + 2K} = \frac{9}{3} = 3 \text{ volts}$$

$$V_A = V_{A1} + V_{A2} = 1 + 3 = 4 \text{ volts} \quad \text{SUM}$$

$V_A = 4 \text{ volts}$

2. How would you calculate V_A without using the Superposition Theorem?

Loop Equations and Kirchhoff's Voltage Law.



LOOP 1 $3V = I_1(2K) + I_1(2K) + I_2(2K)$

$$3V = I_1(2K + 2K) + I_2(2K)$$

LOOP 1 $3 = I_1(4K) + I_2(2K)$

LOOP 2 $9V = I_2(2K + 2K) + I_1(2K)$

LOOP 2 $9 = I_1(2K) + I_2(4K)$

SOLVE 2 simultaneous equations

It is easier to use the SUPERPOSITIONS THEOREM

THEVENIN'S THEOREM

THEVENIN'S THEOREM is used to simplify the solution of circuit problems.

3. Measurement of the open circuit output voltage.

(Momentarily
Remove R_L)

$$V_{out} = E_T = 5.5 \text{ Volts}$$

4. Calculate the expected outputs for various load resistors and enter data in column A.

5. Measure the outputs and enter data in column B.

Load R_L	A	B
	Calculate V_{out} $V_{out} = \frac{E_T R_L}{(R_L + R_T)}$	Measure V_{out}
10K	3.45 V	3.45
1K	0.79 V	0.8
2.2K	1.48 V	1.5
3.3K	1.95 V	1.95
15K	3.93 V	3.95
22K	4.32 V	4.3

6. How do the Measured Voltages (Column B) compare with the Calculated Voltages (Column A)? All values are very close.

7. Calculation of R_T :

from step 3

from step 5

$$R_T = R_L \frac{(E_T - V_{out})}{V_{out}} = (10K) \frac{5.5 - 3.45}{3.45} = 10K \frac{2.05}{3.45}$$

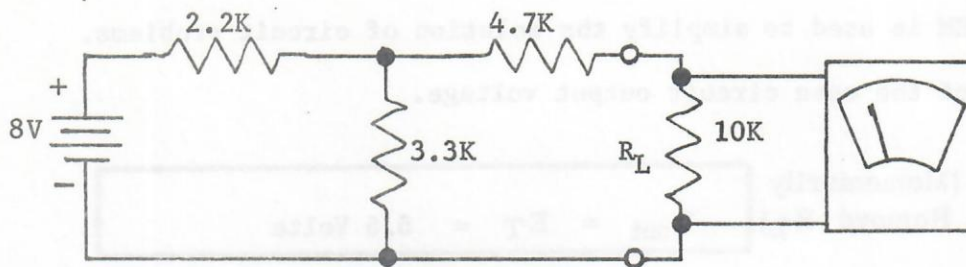
$$R_T = 5.94K \text{ ohms}$$

8. How does the preceding measured R_T compare with the resistance calculation for $R_T = 6K$? The answer is within 1%.

EXERCISES:

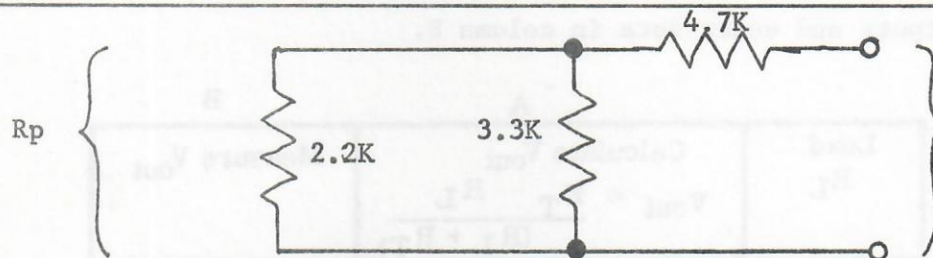
1. Refer to the circuit in Figure 24-1. Consider the condition of $E_1 = 8$ volts, and the load $R_L = 10K$. Calculate the output voltage using Thevenin's Theorem.

THEVENIN'S THEOREM



$$E_T = \frac{8V(3.3K)}{(3.3K + 2.2K)} = \frac{8(3.3)}{(3.3 + 2.2)} = \frac{8(3.3)}{5.5} = 4.8 \text{ volts}$$

To determine E_T
Remove 10K load,
and we have a
simple series
circuit.

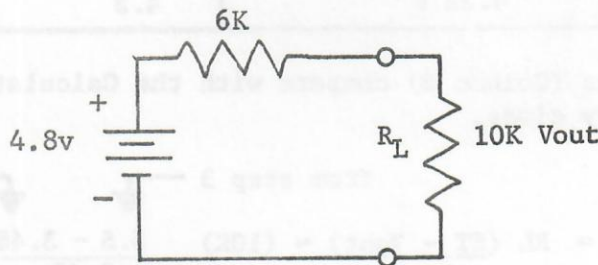


R_T To determine R_T
"short" or
eliminate the 8v
source and
remove R_L .

$$R_p = \frac{(2.2K)(3.3K)}{2.2K + 3.3K} = \frac{2.2K \times 3.3K}{5.5K} = \frac{(2.2)(3.3)K}{5.5} = 1.3K$$

$$R_T = R_p + 4.7K = 1.3K + 4.7K = 6K$$

Thevenin's Equivalent Circuit

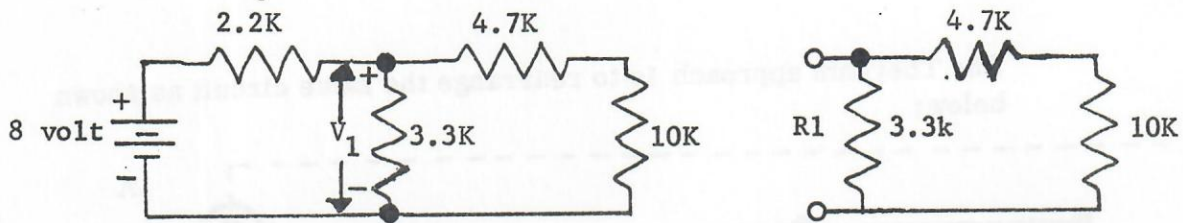


$$V_{out} = \frac{4.8(10)}{10 + 6} = \frac{4.8(10)}{16} = 3 \text{ volts}$$

SIMPLE SOLUTION

2. Calculate the output for the same problem No. 1 above without using Thevenin's Theorem.

THEVENIN'S THEOREM



$R1 = 3.3K$ in parallel with $4.7K + 10K$

$$R1 = \frac{(3.3)(14.7)K}{3.3 + 14.7} = \frac{(3.3)(14.7)K}{18} = 2.7K$$

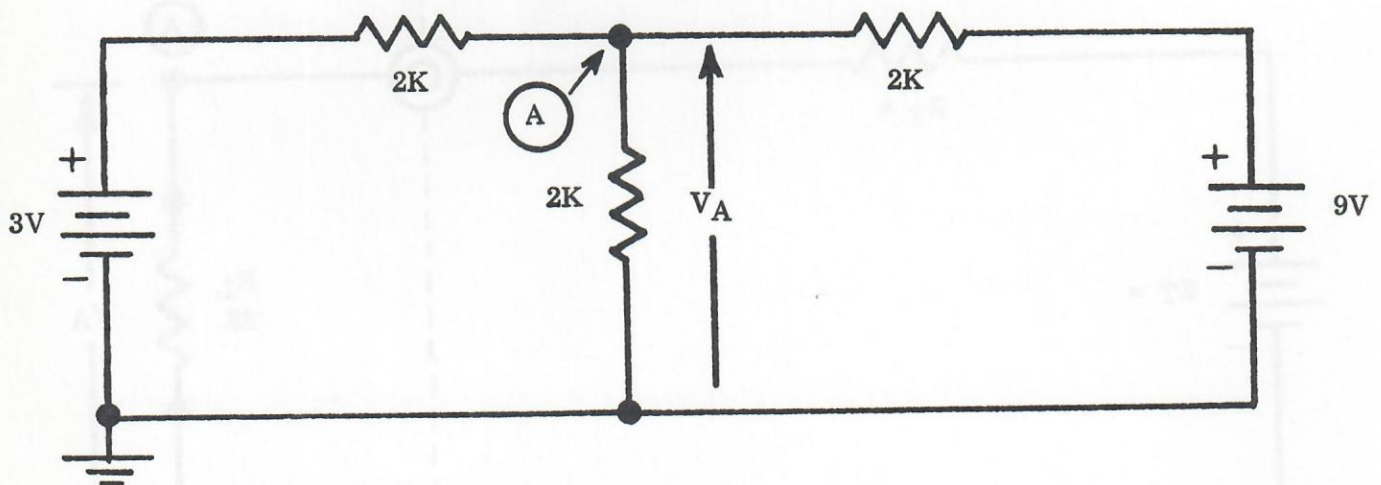
$$V1 = \frac{8(R1)}{R1 + 2.2K} = \frac{8(2.7)}{2.7 + 2.2} = \frac{8(2.7)}{4.9} = 4.4 \text{ volts}$$

Using $V1$ we must calculate the output voltage using the voltage divider equation.

$$V_{out} = \frac{V1(10K)}{10K + 4.7K} = \frac{4.4(10K)}{14.7K} = \frac{4.4(10)}{14.7} = 3 \text{ volts}$$

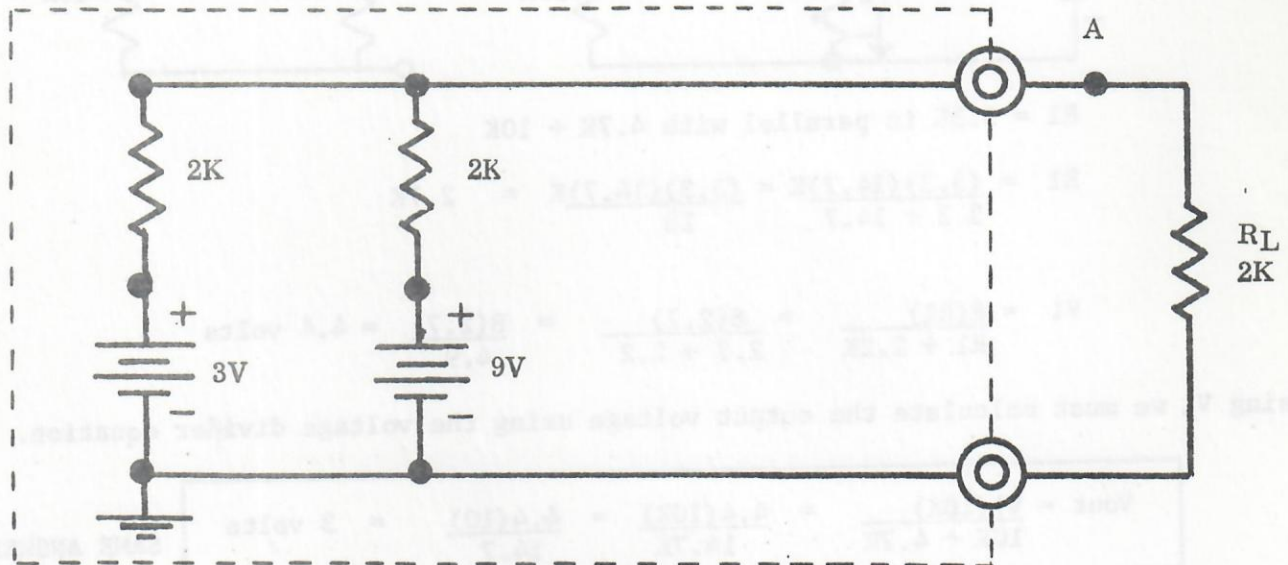
SAME ANSWER

3. Use Thevenin's Theorem, calculate the voltage V_A at point A in the circuit below. This is the same problem we solved using the superposition theorem in the previous experiments.

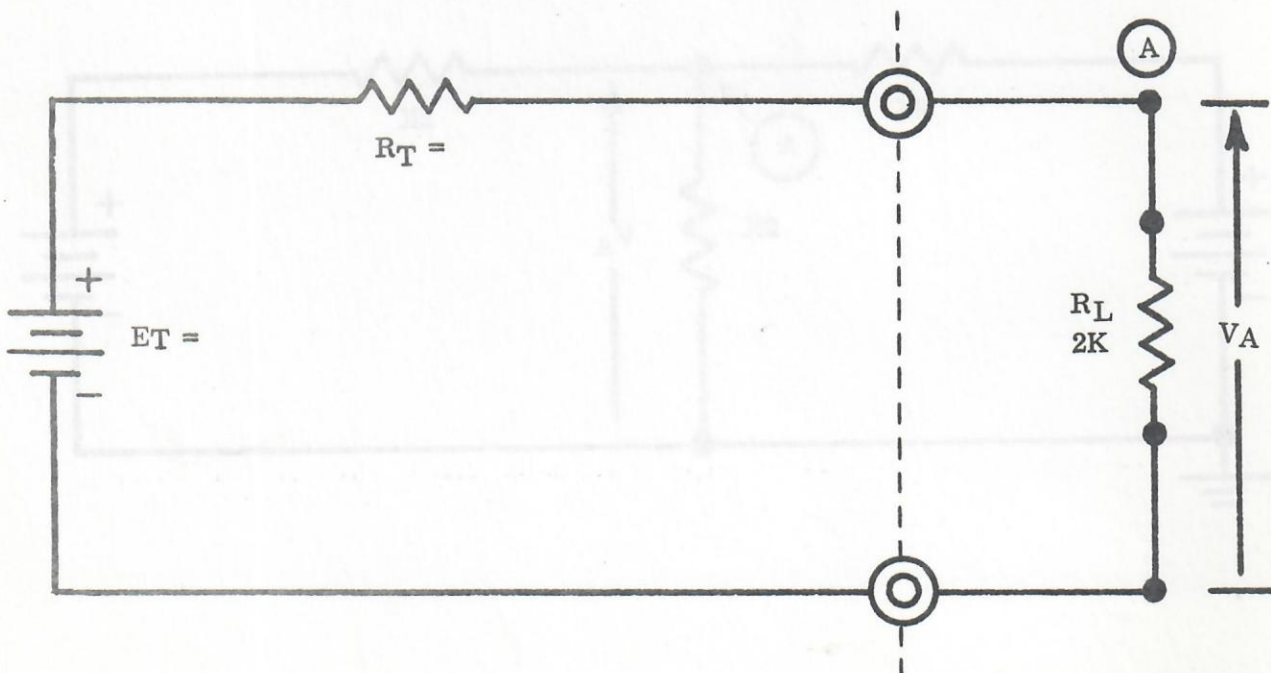


THEVENIN'S THEOREM

The Thevenin approach is to rearrange the same circuit as shown below:



Then, with R_L out of the circuit calculate the equivalent Thevenin parameters E_T and R_T . (The effective loop voltage is 6V.)



THEVENIN'S THEOREM

RT is only the two 2K resistors in parallel.

$$RT = 1K$$

The current in the single loop is:

$$I = \frac{9V - 3V}{4K} = \frac{6}{4K}$$

The Voltage output ET is:

$$ET = 9V - I \cdot 2K$$

$$= 9V - \frac{6}{4K} \cdot 2K = 9 - \frac{6}{2} = 9 - 3$$

$$ET = 6 \text{ volts}$$

Then using the voltage division equations, calculate VA using RL = 2K.

$$VA = \frac{6(2)K}{2 + 1} = \frac{6(2)}{3} = 4 \text{ volts}$$

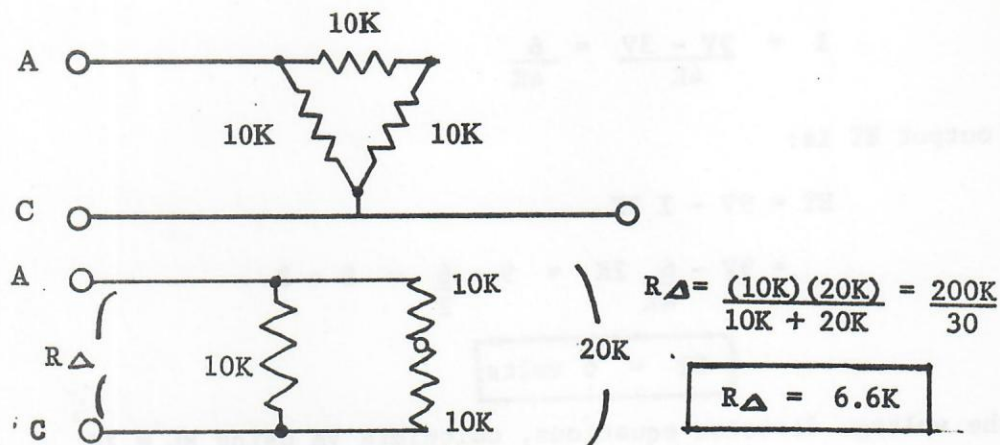
$$VA = 4 \text{ volts}$$

Is this the same voltage output as calculated in Experiment 23, question 1? YES

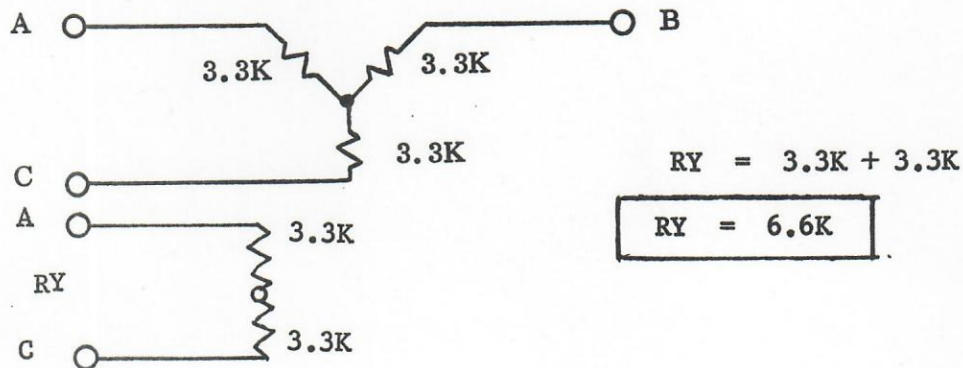
DELTA-WYE CIRCUITS

The Delta and Wye Circuits are studied to show equivalence between the two circuits.

Calculate the equivalent resistance between A and C in the DELTA circuit below (remember series and parallel resistors):



Calculate the equivalent resistance between A and C in the WYE circuit below (only a series circuit):



The calculated resistances are the same between any two ends of the circuit. The circuit operation between A and C is also the same.

PROCEDURE:

Wire the DELTA circuit in Figure 25-1. Measure the output voltage:

$$V_{out} (\Delta) = 2.6 V$$

DELTA-WYE CIRCUITS

1. & 2. Measurement of output voltage of Delta circuit

(note: 2 is a duplicate)

$$V_{out} (\Delta) = 2.6 \text{ volts}$$

4. Measurement of output voltage of Wye circuit.

$$V_{out} (Y) = 2.6 \text{ volts}$$

The output voltage of both circuits is the same indicating that the circuits are equivalent to each other.

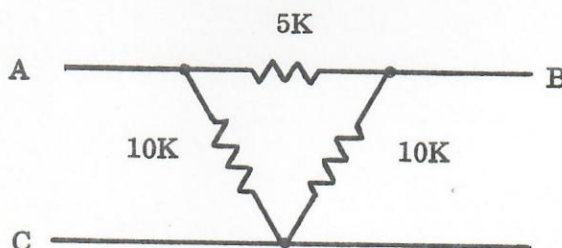
QUESTIONS:

1. Calculate the three input resistances for the Delta circuit below:

$$R_{AB} = \frac{5K(10K + 10K)}{5K + 10K + 10K} = \frac{100K}{25} = 4K$$

$$R_{AC} = \frac{10K(5K + 10K)}{10K + 5K + 10K} = \frac{150K}{25} = 6K$$

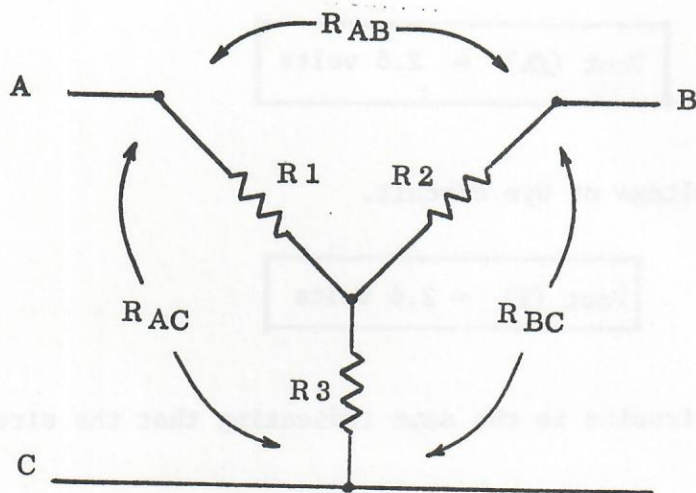
$$R_{BC} = \frac{10K(5K + 10K)}{(10K + 5K + 10K)} = \frac{150K}{25} = 6K$$



R_{AB}	=	4K
R_{AC}	=	6K
R_{BC}	=	6K

DELTA-WYE CIRCUITS

2. Can you guess the equivalent Wye resistances? Note the "symmetry"



$$\begin{aligned} R_{AB} &= 4K \\ R_{AC} &= 6K \\ R_{BC} &= 6K \end{aligned}$$

$$\begin{aligned} R_1 &= 2K \\ R_2 &= 2K \\ R_3 &= 4K \end{aligned}$$

ANSWER

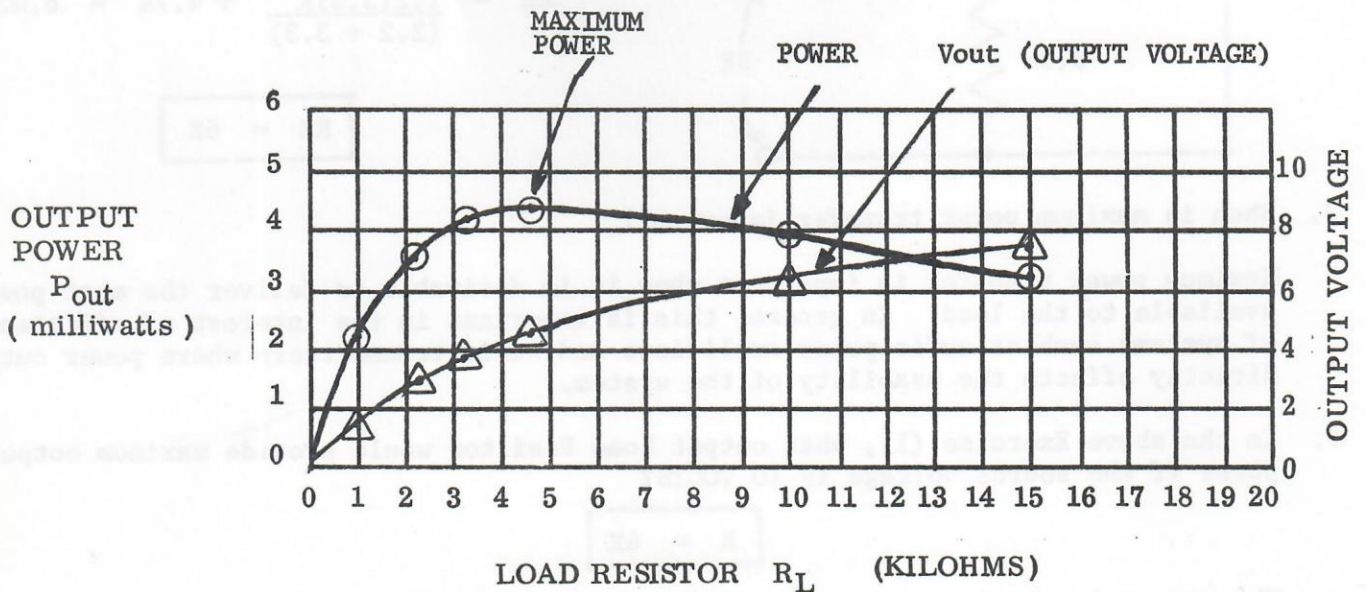
MAXIMUM POWER TRANSFER

This experiment demonstrates experimentally that the maximum power occurs at the LOAD when the load resistor is equal to the source resistance (which is the equivalent Thevenin's Resistance.)

- Measure the Output Voltage and the results in column A.
- Calculate the Power and Enter the results in Column B.

R_L	(A) Measure V_{out}	(B) $P_{out} = \frac{V_{out}^2}{R_L}$
1K	1.5	2.25mw
2.2K	2.8	3.56mw
3.3K	3.7	4.15mw
4.7K	4.5	4.3 mw
10K	6.3	3.97mw
15K	7.1	3.36mw
22K	7.8	2.77mw
33K	8.3	2.09mw
Open circuit	9.6	

- Plot of Power to Load versus Load Resistance.

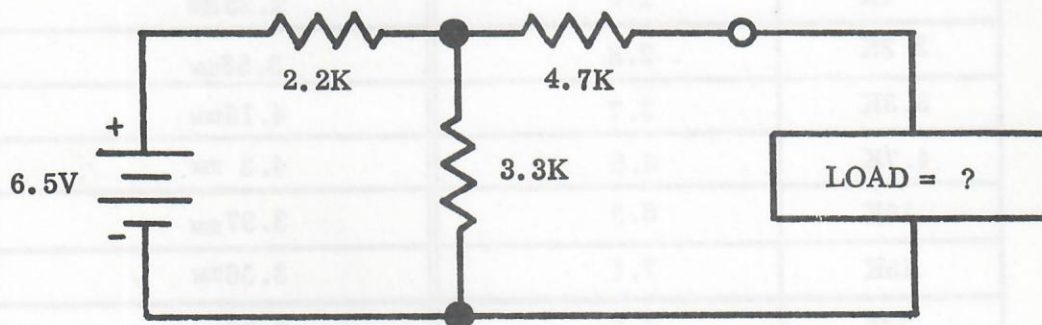


MAXIMUM POWER TRANSFER

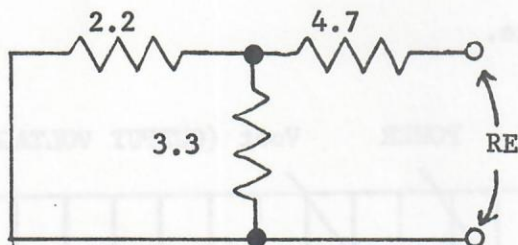
5. Observe the Peak of the power Curve. The maximum power occurs at: $R_L = 4.7K$
7. The output voltage for the various load resistors is plotted in the curve of step 4. The output voltage increases as the Load Resistor increases.

EXERCISES:

1. What Load Resistor should be used for maximum output power in the circuit below?
(Hint: Find Thevenin's Equivalent Resistance first)



EQUIVALENT RESISTANCE



$$R_E = \frac{2.2(3.3)K}{(2.2 + 3.3)} + 4.7K = 6.02K$$

$$R_E = 6K$$

2. When is maximum power transfer important?

Maximum power transfer is important when it is desirable to deliver the most power available to the load. In general this is important in the interest of efficiency of systems such as audio power amplifiers and radio transmitters where power output directly effects the usability of the system.

3. In the above Exercise (1), what output Load Resistor would provide maximum output power if the source voltage is 10 VOLTS?

$$R = 6K$$

The same value load resistor 6K will dissipate the maximum power. Maximum Power Transfer depends upon the source resistance and not on the source voltage.

NORTON'S THEOREM

NORTON'S THEOREM is similar to Thevenin's Theorem, providing an equivalent Current Source with an equivalent Parallel Resistance. It is useful when the source resistance is high and the load resistances are small. Then the equivalent circuit can just be considered as a current source.

2. Measurement of +V2 Power Source Voltage.

$$+V2 = 9.7 \text{ volts}$$

3. Calculation of Norton's Current Source.

$$I = \frac{+V2}{R} = \frac{(+V2)}{6K} = \frac{(9.7)}{6K} = 1.6 \text{ ma}$$

NORTON'S
CURRENT

$$I = 1.6 \text{ ma}$$

$$V_e = IR_L = (1.6)\text{ma} (R_L)$$

R_L	(A) $V_e = IR_L$ CALCULATION	(B) V_{out} MEASUREMENT
100	0.1	0.09 volts
200	0.2	0.18 volts
50	0.05	0.05 volts
500	0.5	0.44volts
1K	1.0	0.8 volts

7. How do the measured voltages (Column B) compare with the calculated voltages (Column A)?

The agreement is very good. All orders of magnitude are correct and the voltages are generally within 20% of each other.



Ed-Lab

ANSWER MANUAL

DIODES and OTHER DEVICES

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UNIT NO.
CES INDUSTRIES, INC.

PHOTOCELL RESISTANCE

The photocell is used in a voltage divider and in a bridge circuit. When the light impinging on the photocell changes, the resistance of the photocell will change causing an output voltage change because of the variations in the voltage divider ratio. When the photocell resistance decreases the output voltage will increase and vice-versa.

2. Measurement of source voltage V_s .

$$V_s = 9.8 \text{ volts}$$

3. Tabulation of output voltage for various light levels. Note: Each student will get different results in their column.

Light on Photocell Block with your hand	MEASURE V_{out} (A)	CALCULATE R_p (B)
UNCOVERED	7.4	3.2K
HAND (2 FEET AWAY)	7.2	3.6K
(6 INCHES)	6.4	5.3K
(3 INCHES)	3.6	17.2K
COMPLETELY COVERED	0.8	112.5K

4. The calculation of the photocell resistance for each output voltage listed above is tabulated in the right hand column of the table in step 3.

$$V_{out} = \frac{9.8 (10K)}{10K + R_p}, \quad 10K + R_p = \frac{9.8 (10K)}{V_{out}}, \quad R_p = \frac{9.8 (10K)}{V_{out}} - 10K$$

8. Comment on the operation of the bridge circuit. What variation in voltage occurs with light variation?

The meter reading will change 0.25V with light variation but a very small change in light intensity will cause this half scale variation.

Note: The reason that the meter variation is restricted to 0.25 volts is because the meter is used on the 0.5 volt scale and this is the maximum voltage variation that can be read on the meter.

SWITCH ON-OFF CONTROL

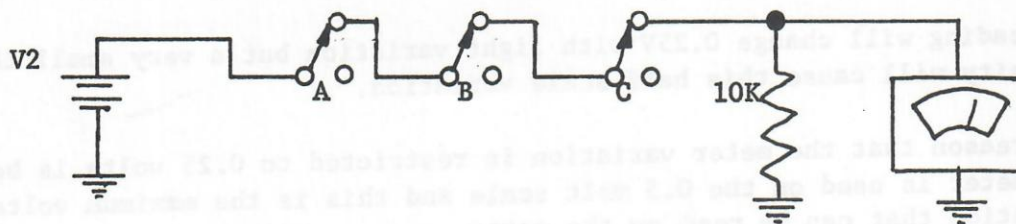
Single pole double throw switches are connected in such a way as to light a lamp under only certain specified conditions. This serves as an introduction to the concept of switching logic and also familiarizes the student with the use of switches.

1. Table of output voltage and logic levels for the example:

SWITCHES			1 = UP 0 = DOWN	OUTPUT VOLTAGE (meter reading)	OUTPUT VOLTAGE 1 = YES 0 = NO
A	B	C			
0	0	0		0	0
0	0	1		9.8 v	1
0	1	0		0v	0
0	1	1		9.8 v	1
1	0	0		0v	0
1	0	1		9.8 v	1
1	1	0		9.8 v	1
1	1	1		9.8 v	1

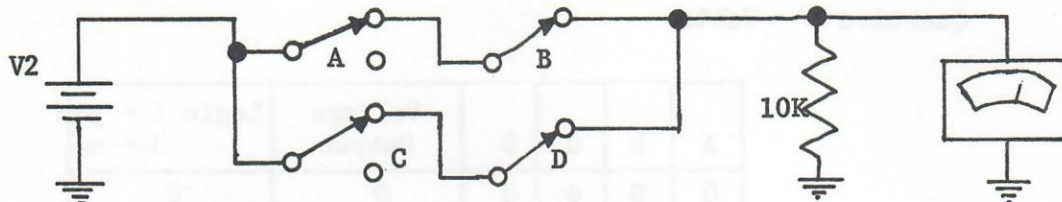
QUESTIONS:

1. Draw the circuit with 3 switches where the output voltage will be ON only when all 3 switches are UP.

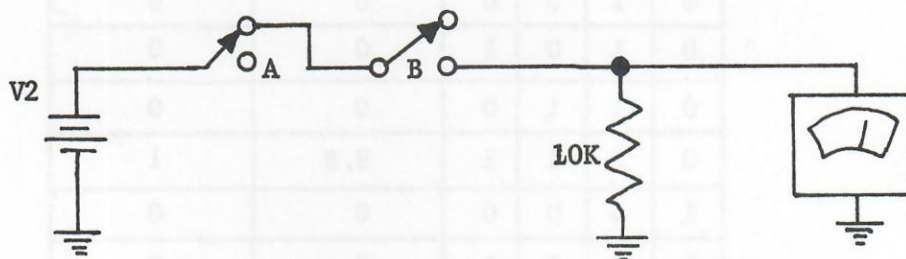


SWITCH ON-OFF CONTROL

2. Draw the circuit using 4 switches A, B, C, D where the output voltage will be ON when A AND B are UP OR when C AND D are UP.



3. Draw a circuit using 2 switches where the output voltage is ON only when Switch A is UP and Switch B is DOWN.



4. Prepare tables as above for the three circuits given in above questions 1, 2, & 3.

Question 1: Table

A	B	C	Voltage Output	Logic 1 = yes 0 = no
0	0	0	0	0
0	0	1	0	0
0	1	0	0	0
0	1	1	0	0
1	0	0	0	0
1	0	1	0	0
1	1	0	0	0
1	1	1	8	1

SWITCH ON-OFF CONTROL

Question 2 - Table

A	B	C	D	Voltage Output	Logic 1 = yes 0 = no
0	0	0	0	0	0
0	0	0	1	0	0
0	0	1	0	0	0
0	0	1	1	9.8	1
0	1	0	0	0	0
0	1	0	1	0	0
0	1	1	0	0	0
0	1	1	1	9.8	1
1	0	0	0	0	0
1	0	0	1	0	0
1	0	1	0	0	0
1	0	1	1	9.8	1
1	1	0	0	9.8	1
1	1	0	1	9.8	1
1	1	1	0	9.8	1
1	1	1	1	9.8	1

Question 3 - Table

A	B	Voltage Output	Logic 1 = yes 0 = no
0	0	0	0
0	1	0	0
1	0	9.8v	1
1	1	0	0

POTENTIOMETER ANALOG COMPUTER

Two potentiometers are connected in series to generate ratio multiplication. The output level is scaled with a third potentiometer to result in a direct reading analog computer system.

3. Tabulation of inputs and outputs for the analog computer.

MULTIPLICATION KNOB INPUTS		METER OUTPUT
S (1K) POT mph	H (100K) POT hours	M (meter) miles
50	4	200
20	2	40
30	4	130
60	3	170
25	3½	85
40	1	45
50	2½	110
55	5	280

← SET 1M POT FOR 200.
(CALIBRATION)

4. Do the results check? The results are within 10% of the expected value.

POTENTIOMETER ANALOG COMPUTER

DIVISION

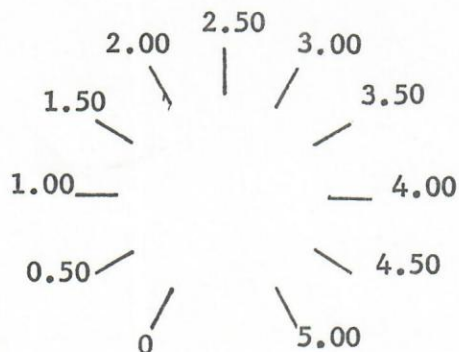
INPUT SET		OUTPUT ADJUST	INPUT
H 100K POT hours		S (1K POT) speed / mph	M METER (miles)
3		10	30
5		80	400
4		50	200
3		30	100
1		40	40
2½		25	65
3		60	175
3		67	190

QUESTIONS:

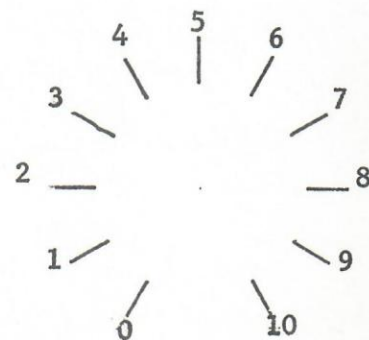
1. Draw a set of scales for POTS S and H, and the METER M to perform multiplication to determine

COST PER POUND x POUNDS = TOTAL COST

(e.g., for a maximum rate of \$5. per pound times a maximum of 10 pounds resulting in a total maximum of \$50.00)



COST PER POUND, DOLLARS PER POUND

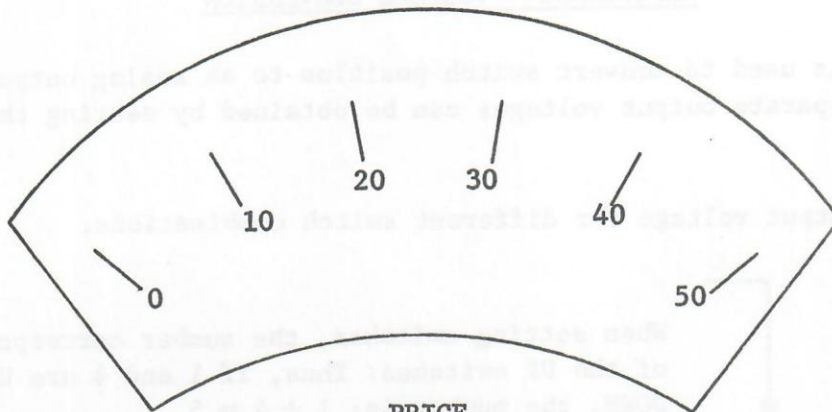


POUNDS

POTENTIOMETER ANALOG COMPUTER

UNIT 2
EXPERIMENT NO. 3
Page 3

METER SCALE



PRICE
DOLLARS

SWITCHES SET FOR	METER VOLTS
0	0
1	1.0
2	2.0
3	3.0
4	4.0
5	5.0
6	6.0
7	7.0

RESISTANCE - VOLTAGE CONVERSION

A resistor network is used to convert switch position to an analog output voltage on a voltmeter. Eight separate output voltages can be obtained by setting the switches in various positions.

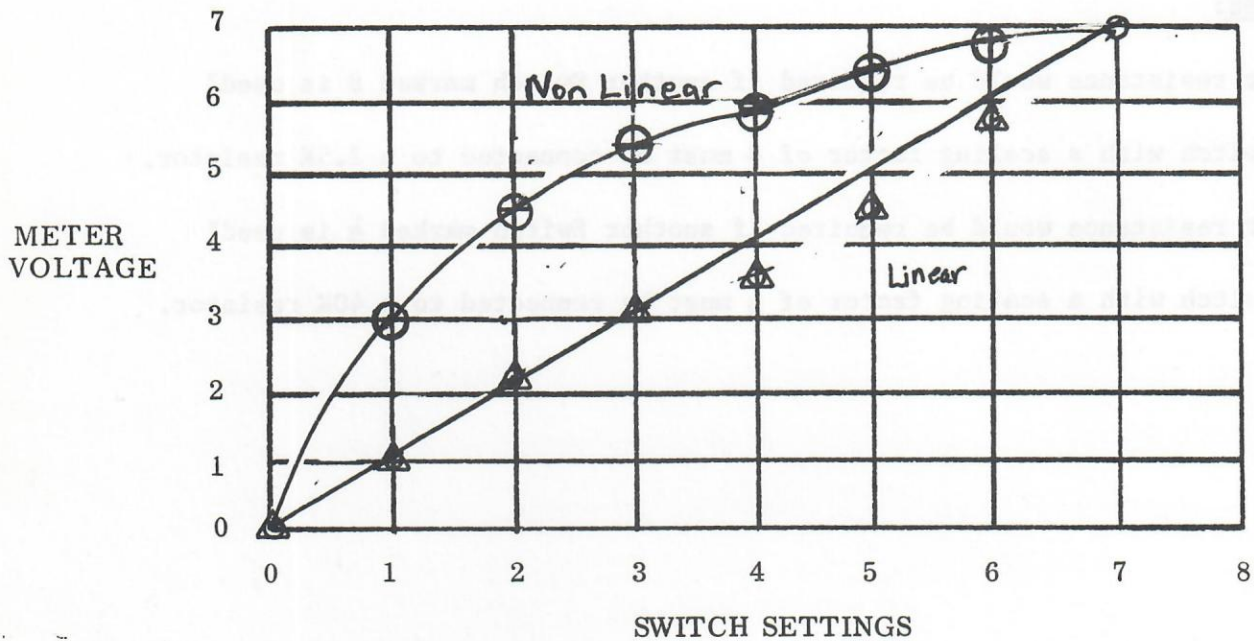
3. Tabulation of output voltage for different switch combinations.

When setting switches, the number corresponds to the sum of the UP switches: Thus, if 1 and 4 are UP, and 2 is DOWN, the number is: $1 + 4 = 5$

SWITCHES SET FOR	METER VOLTS
0	0
1	1.0
2	2.1
3	3.2
4	3.6
5	4.3
6	5.9
7	7.0

← FIRST
CALIBRATE

RESISTANCE - VOLTAGE CONVERSION



8. Tabulation of the output voltages for different switch positions for the Non Linear Circuit.

SWITCHES	METER (on 10 scale)
0	0
1	3.0
2	4.5
3	5.6
4	5.8
5	6.3
6	6.6
7	7.0

FIRST
CALIBRATION

9. Data is plotted on graph of step 4.
10. How does the non-linear converter compare with the linear Digital to Analog Converter?
The Non-Linear converter curve shown in the graph of step 4 has an upward curve in the center of its range, departing from a straight line.

RESISTANCE - VOLTAGE CONVERSION

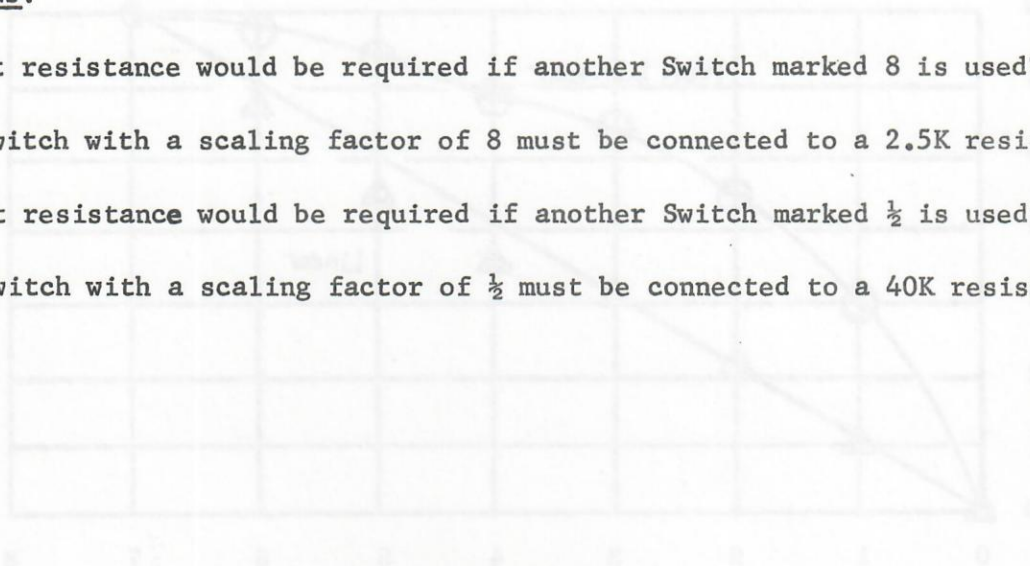
QUESTIONS:

1. What resistance would be required if another Switch marked 8 is used?

A Switch with a scaling factor of 8 must be connected to a 2.5K resistor.

2. What resistance would be required if another Switch marked $\frac{1}{2}$ is used?

A Switch with a scaling factor of $\frac{1}{2}$ must be connected to a 40K resistor.



SWITCHES	METER (on 10 scale)
0	0
1	2.5
2	5.0
3	7.5
4	10.0
5	12.5
6	15.0
7	17.5
8	20.0

FIRST
CALIBRATION

9. Data is plotted on graph of step 4.
 10. How does the non-linear converter compare with the linear Digital-to-Analog Converter?
- The non-linear converter curve shows in the graph of step 4 has an upward curve in the center of its range, departing from a straight line.

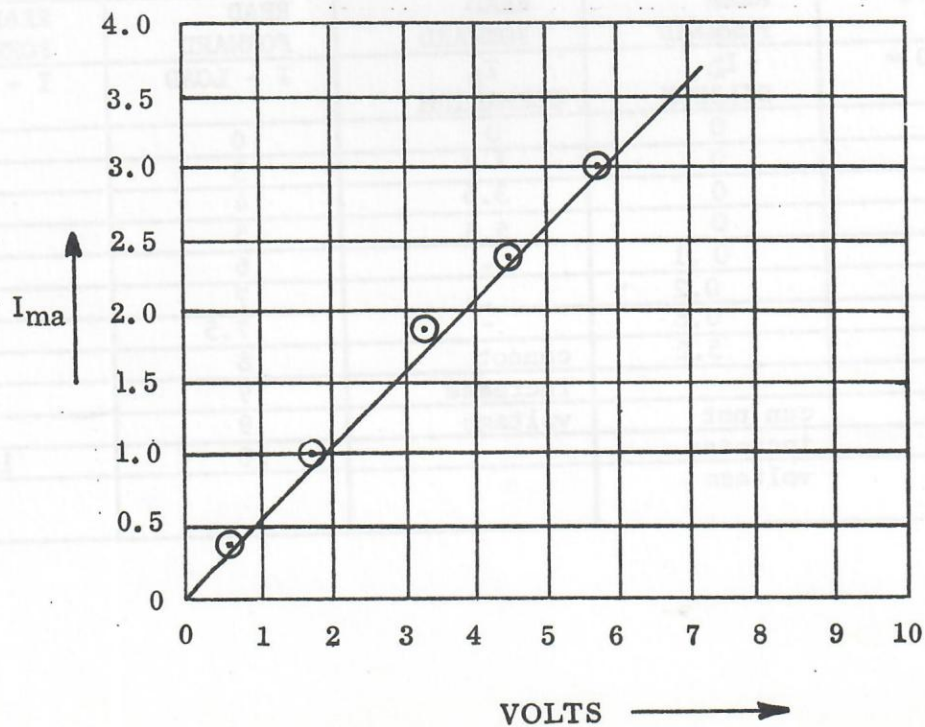
RESISTANCE & DIODE MEASUREMENTS

The current versus Voltage characteristic of a resistor, diode and lamp is measured. The current is measured by measuring the voltage across a 1K series resistor. The voltage across the device under test is measured directly.

2. Table of Measurements for the 2.2K resistor.

APPROXIMATE KNOB POSITION (+V1 VARIATION)	RESISTOR $R_u = 2.2K$ (USE 10 FULL SCALE)	
	V_R VOLTS SWITCH C DOWN	I_R MILLIAMPS SWITCH C UP
0	0	0
2	0.7 volts	0.4 ma
4	1.8 volts	1.0 ma
6	3.3 volts	1.8 ma
8	4.5 volts	2.4 ma
10	5.8 volts	3.0 ma

3. Graph of Data recorded in the Table of step 2.



RESISTANCE & DIODE MEASUREMENTS

4. Calculation of the resistor under test from the voltage and current data. The voltage is divided by the current for various data points taken in step 2 to calculate the resistor under test. This is used as a test of the accuracy of the data taken.

KNOB POSITION	V_R	I_R	CALCULATE $R = \frac{V_R}{I_R}$
2	0.7 volts	0.4 ma	1.75K
6	3.3 volts	1.8 ma	1.8 K
10	5.8 volts	3.0 ma	1.9 K

5. Is the value of R the same at different voltage and current conditions?

The resistance calculated at POT position 2 is 1.75K

The resistance calculated at POT position 10 is 1.9K

The % Error between the two readings is:

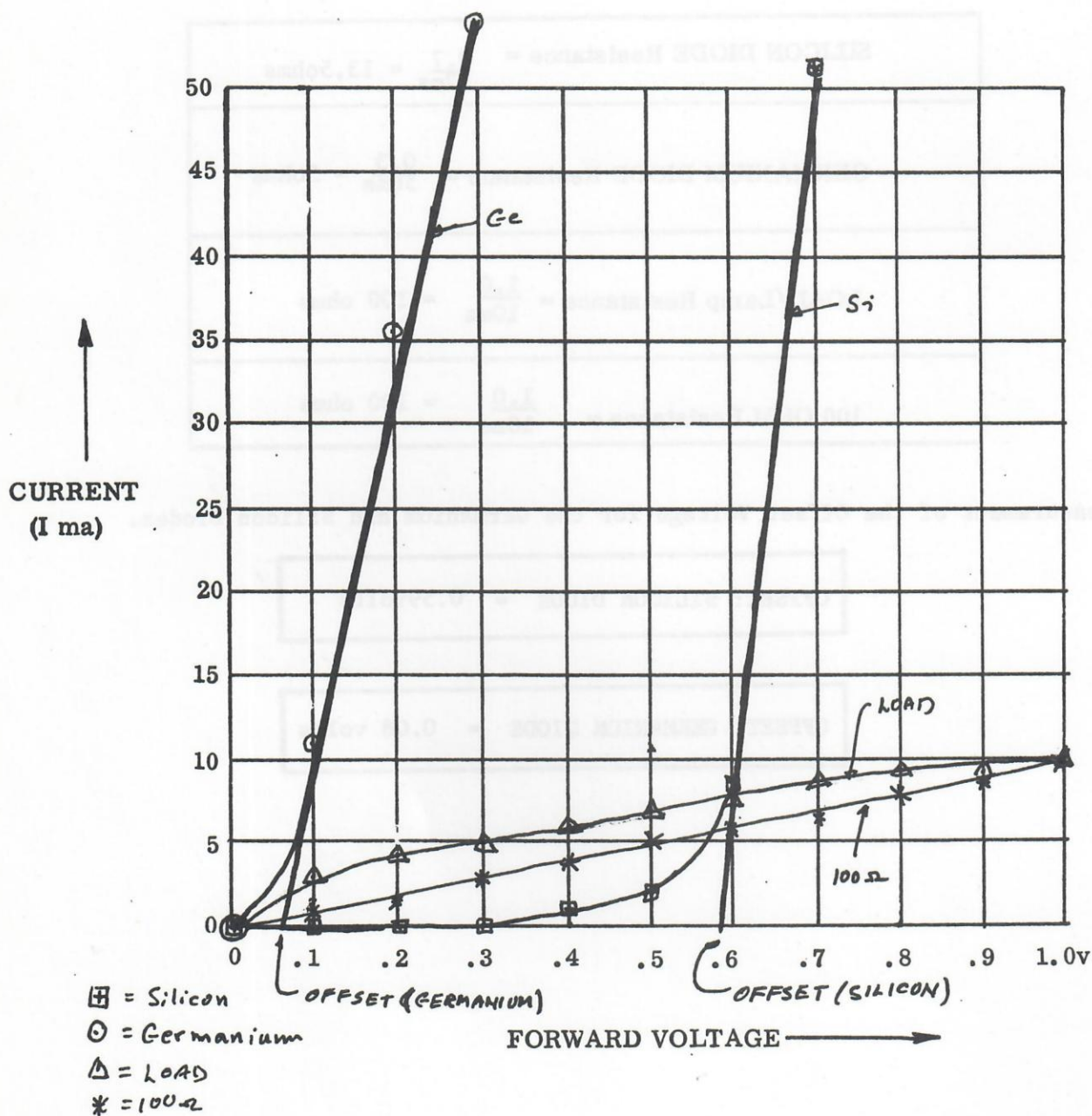
$$\% \text{ Error} = \frac{1.9 - 1.75}{1.9} \times 100 = 7.9\%$$

9,10,11,12. Measurement of Voltage versus Current for the Silicon Diode, the Germanium Diode, the Lamp and the 100 ohm resistor.

SET +V1	COLUMN A READ FORWARD	COLUMN B READ FORWARD	COLUMN C READ FORWARD	COLUMN D READ FORWARD
FOR VD =	I_D SILICON	I_D GERMANIUM	I - LOAD	I - 100ohm
0	0	0	0	0
.1	0	1.2	3	1
.2	0	3.6	4	2
.3	0	5.6	5	3
.4	0.1	-	6	4
.5	0.2	-	7	5
.6	0.8	-	7.5	6
.7	5.2	cannot	8	7
.8	-	increase	9	8
.9	can not	voltage	9	9
1.0	increase voltage		10	10

RESISTANCE & DIODE MEASUREMENTS

13. Graph of the Voltage versus Current data from the table in step 9.



14. Calculate the resistance of each device at the highest current reading. Comment on the results.

The resistance of each device is calculated by picking a particular voltage/current point on the curve of step 13 or data in step 9. The voltage divided by the current flowing in the device at that voltage is the device resistance.

RESISTANCE & DIODE MEASUREMENTS

SILICON DIODE Resistance = $\frac{0.7}{52\text{ma}}$ = 13.5ohms
GERMANIUM DIODE Resistance = $\frac{0.3}{56\text{ma}}$ = 5ohms
LOAD/Lamp Resistance = $\frac{1.0}{10\text{ma}}$ = 100 ohms
100 OHM Resistance = $\frac{1.0}{10\text{ma}}$ = 100 ohms

15. Measurement of the Offset Voltage for the Germanium and Silicon Diodes.

OFFSET: SILICON DIODE = 0.59volts

OFFSET: GERMANIUM DIODE = 0.08 volts

BRIDGE A.C. METER

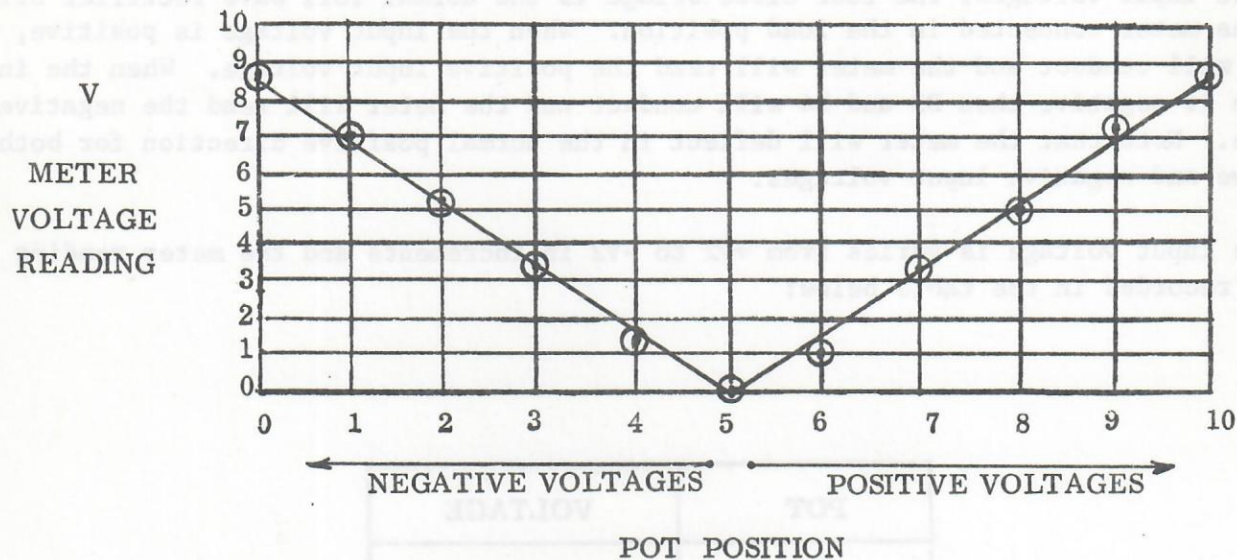
A voltmeter is placed in a bridge circuit so the meter will measure both positive and negative input voltages. The four diode bridge is the normal full wave rectifier bridge with the meter connected in the load position. When the input voltage is positive, D1 and D2 will conduct and the meter will read the positive input voltage. When the input voltage is negative then D3 and D4 will conduct and the meter will read the negative voltage. Note that the meter will deflect in the normal positive direction for both positive and negative input voltages.

2. The input voltage is varies from +V2 to -V2 in increments and the meter reading is recorded in the table below:

POT	VOLTAGE
0	8.8
1	7.0
2	5.2
3	3.4
4	1.4
5	0
6	1.0
7	3.2
8	5.0
9	7.2
10	8.8

BRIDGE A.C. METER

3. The results tabulated in the table of step 2 are plotted:



QUESTIONS:

1. What occurs if all diodes are reversed in the circuit?

If all the diodes are reversed the bridge will direct current to the meter in the wrong direction and the meter will read below zero.

2. What occurs if only diodes D3 and D4 are reversed?

The diodes D3 and D4 will then conduct for all positive input voltages along with diodes D1 and D2. Therefore, the input voltage will be shorted directly to ground and the meter will read zero at all times. When the input voltage is negative, all the diodes will be reverse biased and the meter again will read zero.

3. What occurs if diodes D3 and D4 are removed?

Without diodes D3 and D4 the path through the meter for negative input voltages is removed and the meter will only read positive input voltages.

4. What if diodes D1 and D2 are removed and D3 and D4 are left in the circuit?

Without D1 and D2 the path through the meter for positive input voltages is removed and the meter will read only negative input voltages.

DIODE "OR" LOGIC

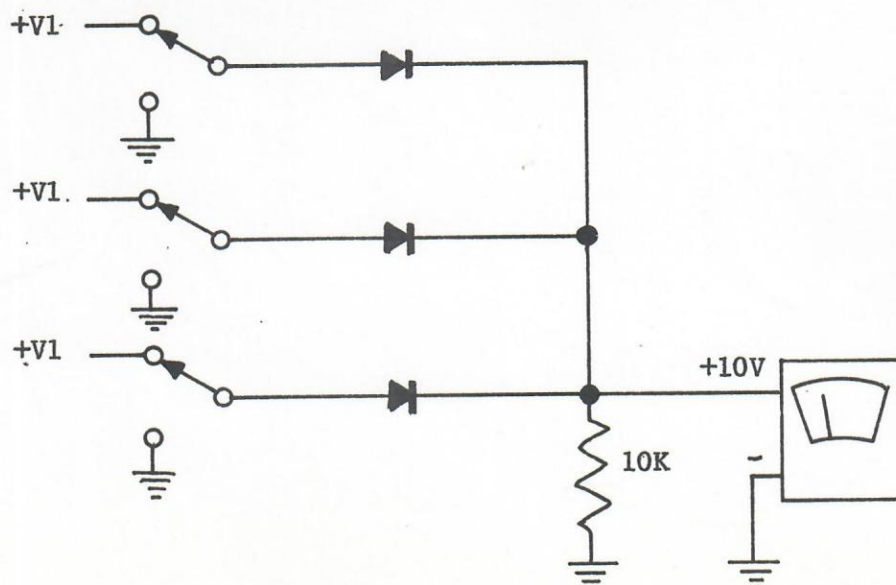
Two diodes are connected to a load so that when power is applied to one OR, the other of the diodes current will flow in the load. This is the Logical OR function and it serves to demonstrate the operation of the logical OR gate and the application of diodes in implementing this function.

3. Tabulation of output (ON or OFF) for various switch positions.

INPUTS		OUTPUT
SWITCH A	SWITCH B	VOLTAGE (ON or OFF)
DOWN	DOWN	OFF
DOWN	UP	ON
UP	DOWN	ON
UP	UP	ON

QUESTIONS:

1. How would you add Switch C as an additional OR input to control the OUTPUT VOLTAGE?



DIODE "AND" LOGIC

Diode elements are used to produce the AND Function. Switches A and B apply either a voltage or ground to the cathodes of diodes D1 and D2 respectively. When either switch A or B is DOWN current will flow in the diode and the output will be shorted to ground. When switches A and B are UP then both diodes will be OFF and the meter will read the source voltage V1 through the 1K resistor.

2. Tabulation of output for various switch positions.

INPUTS		OUTPUT
A	B	ON or OFF
DOWN	DOWN	OFF
DOWN	UP	OFF
UP	DOWN	OFF
UP	UP	ON

3. Are the results correct?

Yes. The output is ON only when switch A and switch B are UP.



DIODE "AND-OR" LOGIC

The AND and the OR circuit of the two preceeding experiments are combined to obtain a AND-OR logic element.

The logic equation for this circuit is $(A \cdot B) + C = X = (A \text{ and } B) \text{ or } C$

1. Tabulation of predicted outputs for switch settings.

INPUT SWITCHES			OUTPUT	
1 is UP 0 is DOWN			1 for ON 0 for OFF	
A	B	C	PREDICT "X"	TEST
0	0	0	0	0
0	0	1	1	1
0	1	0	0	0
0	1	1	1	1
1	0	0	0	0
1	0	1	1	1
1	1	0	1	1
1	1	1	1	1

4. Do the actual test outputs agree with the predicted output?

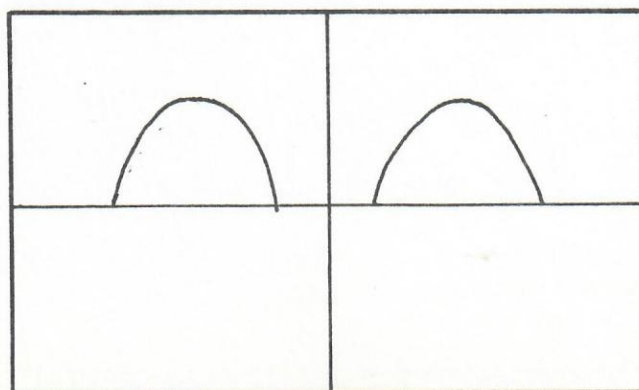
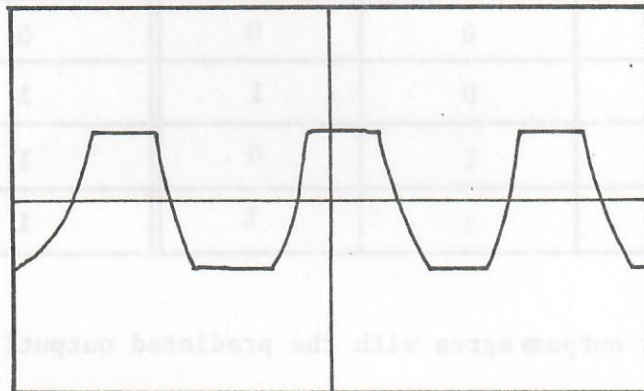
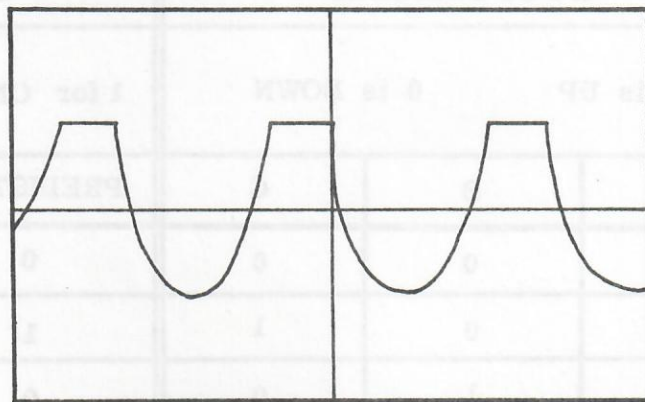
Yes. They are the same.



SINE WAVE AND DIODE CLIPPER

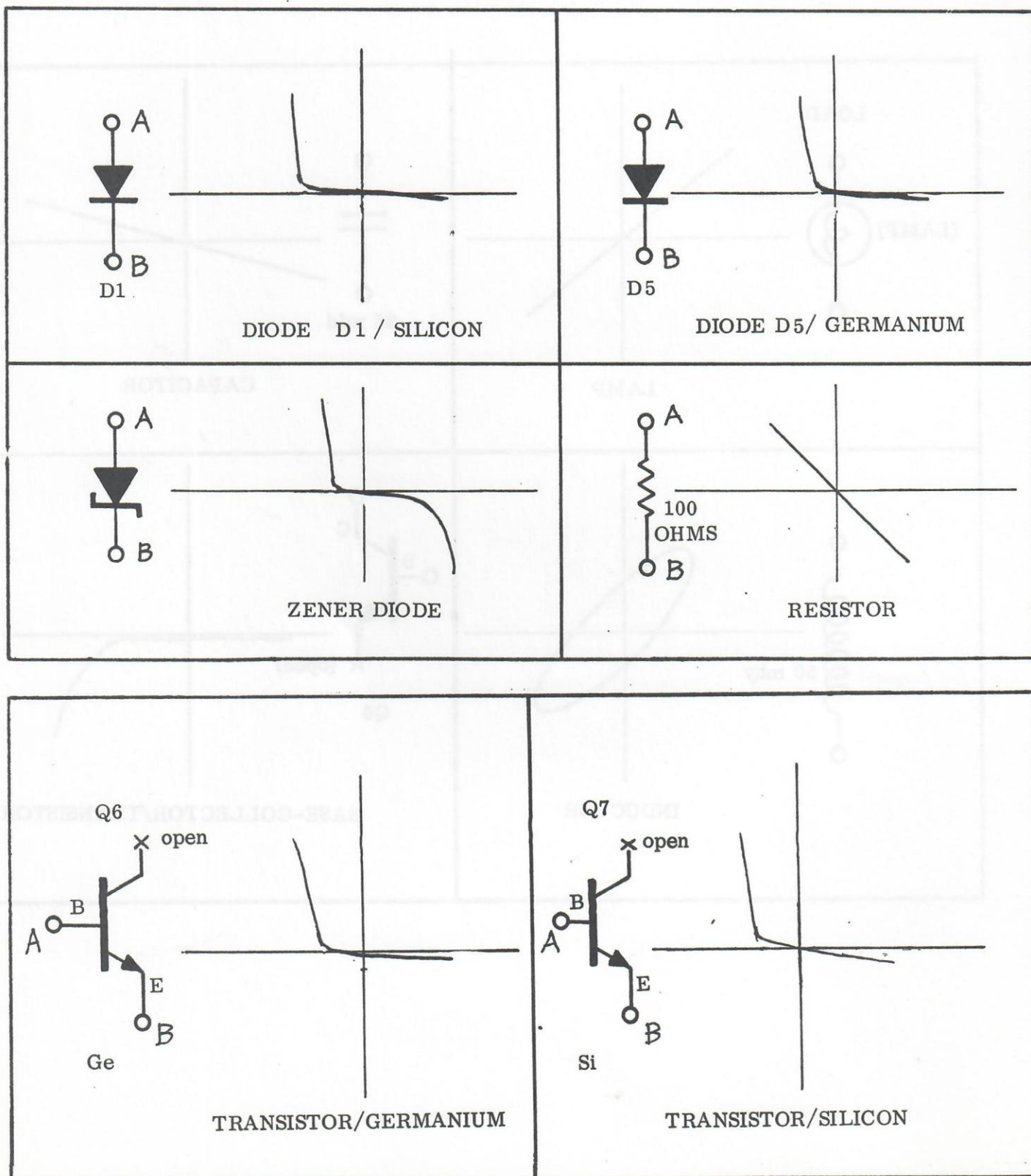
The sine wave A.C. source is provided by the transformer. When the sine wave voltage at point A increases above the setting of V_1 , diode D_1 will conduct and the positive sine wave voltage will be clipped at V_1 . When the sine wave voltage drops below the voltage at the wiper of the 1K pot the diode D_2 will conduct and the output signal will be clipped at this level. Thus, the positive and negative sine wave peaks can be clipped at any desired voltage level.

3. Waveform outputs from clipper circuit.

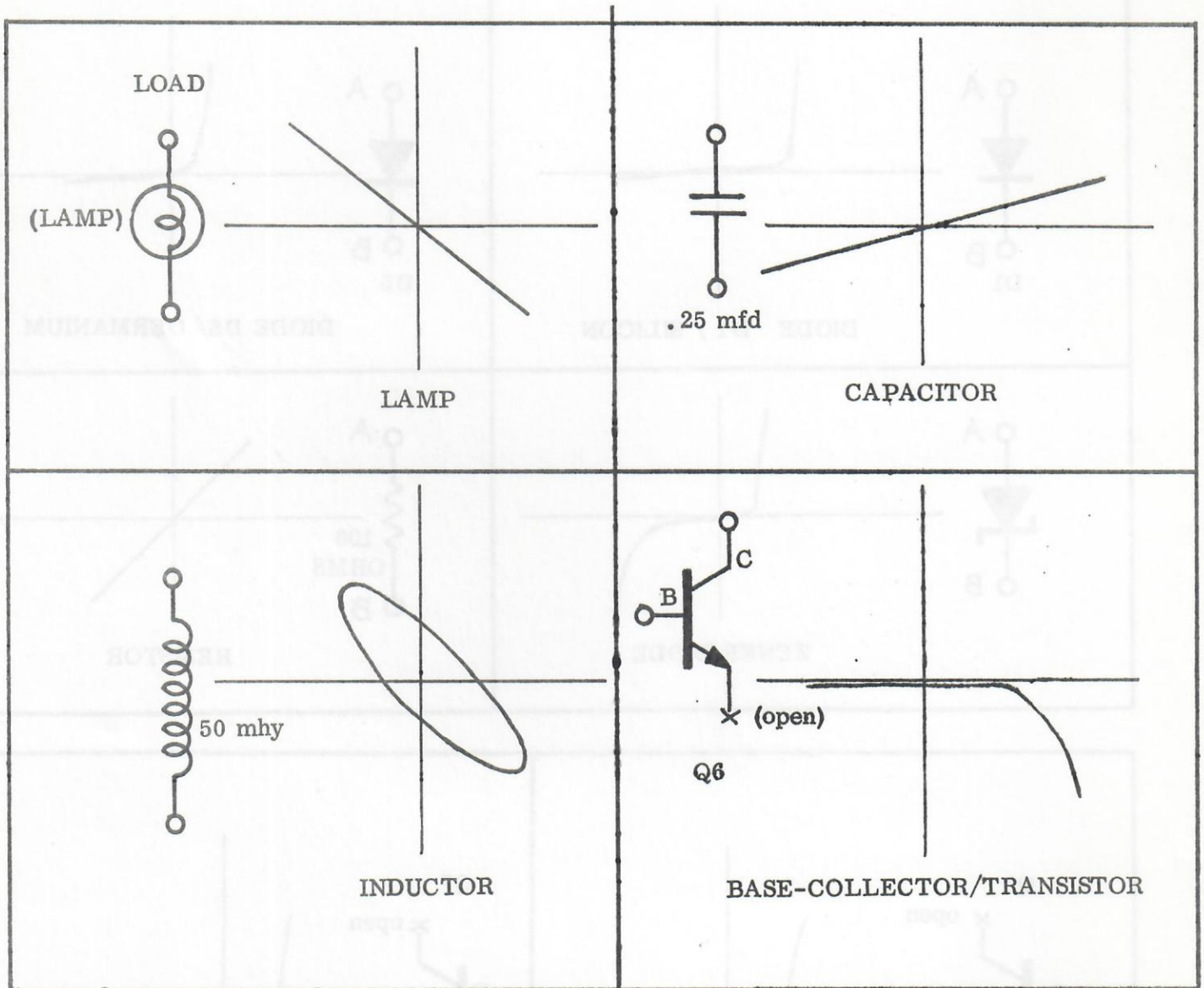


DIODE CHARACTERISTIC CURVE TRACER

A curve tracer is used to display the characteristic curve of a diode and of other devices.



DIODE CHARACTERISTIC CURVE TRACER



ELECTRONIC CIRCUIT MEASUREMENTS

Voltage measurements are made on an electronic circuit containing resistors, diodes and transistors and verify the voltage law for the loops in the circuit.

2. Tabulation of all voltages in the circuit under test.

Voltage	Measurement
V_s	9.7 volts
V_{out}	5.3 volts
V_1	4.0 volts
V_2	3.0 volts
V_3	2.2 volts
V_4	0.4 volts
V_5	2.4 volts
V_6	2.3 volts
V_7	2.9 volts
V_8	0.2 volts

3. Verification of Kirchhoff's Voltage Law for: $V_1 + V_2 + V_3 = V_s$

OUTPUT CIRCUIT

V_1	4.0 volts
V_2	3.0 volts
V_3	2.2 volts
SUM	9.2

compare to

$V_s = 9.7$

4. Does the Voltage Law check properly? YES

Verification of Kirchhoff's Voltage Law for other circuit loops.

ELECTRONIC CIRCUIT MEASUREMENTS

Collector (C) Output

V_2	=	3.0
V_3	=	2.2
Sum		5.2

compare to

$$V_{out} = 5.3$$

Feedback Circuit

V_4	0.4
V_5	2.4
V_6	2.3
Sum	5.1

compare to

$$V_{out} = 5.3$$

Transistor Junction

V_7	2.9
V_8	0.2
Sum	3.1

compare to

$$V_2 = 3.0$$

Loop

V_6	+	2.3
V_5	+	2.4
V_4	+	0.4
V_7	-	2.9
V_8	-	0.2
V_3	-	2.2
Sum		-0.2

should be 0

5. Do these calculations verify the Voltage Law? YES

ELECTRONIC CIRCUIT MEASUREMENTS

QUESTIONS:

1. Use OHMS law to calculate the current in R_c .

$$I_c = \frac{V_1}{R_c} = \frac{4.0}{3.3K} = 1.212\text{ma}$$

$$I_c = 1.212 \text{ ma}$$

2. Calculate the current in R_e :

$$I_e = \frac{V_3}{R_e} = \frac{2.2}{2.2K} = 1\text{ma}$$

$$I_e = 1 \text{ ma}$$

3. Calculate the currents in R_f and R_b

$$I_f = \frac{V_5}{R_f} = \frac{2.4}{10K} = 0.24\text{ma}$$

$$I_b = \frac{V_6}{R_b} = \frac{2.3}{10K} = 0.23\text{ma}$$

4. Calculate the transistor current, I_T .

Use Kirchoff's Current Law.

$$I_T = I_c - I_f$$

$$I_T = 1.21 - 0.24 = 0.97$$

PHOTOCELL BRIDGE

A photocell drives an active transistor amplifier circuit so that the variations in light level can control a lamp.

3. Block the light to the photocell, and observe that you can control the lamp to be ON and OFF. What is the furthest distance from the photocell that you can control the LAMP?

The lamp turns on when the hand is placed about one foot in front of the photocell. (Note: The students answers will vary depending upon the ambient light level in the laboratory.)

4. Does the lamp turn ON and OFF sharply, or can you control various shades of brightness?

The brightness of the lamp can be controlled by carefully controlling the position of the hand in front of the photocell but the circuit is very sensitive and the lamp goes on and off for very small variations in light intensity.

SENSITIVE MICROAMMETER

A transistor driven microammeter is used to measure very small currents.

Supply Voltage:

+V2 = 9.8 volts

Calculation of Calibration Current:

$$I = \frac{+V2}{2M} = \frac{9.8 \text{ microamperes}}{2 \times 10^6} \quad (\text{APPROX } 4.9 \mu a)$$

4. Tabulation of measured and theoretical currents for various resistors.

	(A)	(B)
Ru	I _m Measured CURRENT	I _c = +V2/Ru
4.7 M	1.8 ua	2.08 ua
* (4.7M + 1M) 5.7 M	1.25 ua	1.72 ua
* (4.7M + 1M + 1M) 6.7 M	1ua	1.46 ua

QUESTIONS:

1. How would you use the circuit to provide a full scale reading of 1 MICROAMP?

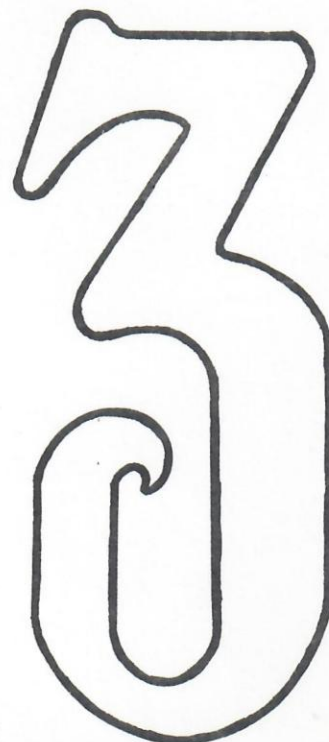
The system must be recalibrated for full scale of 1 μa by placing a 10 meg calibration resistor in the calibrated position and adjusting the 1K shunt POT for 0.96 μa .



Ed-Lab
ANSWER MANUAL

BASIC A.C. CIRCUITS

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UNIT NO.
CES INDUSTRIES, INC.

OSCILLOSCOPE AND SINE-WAVES

An Audio Signal Generator is used as a signal source and the A.C. meter and oscilloscope are used to monitor the signal outputs. The frequency response of a resistive voltage divider is tested and the fact that resistors behave the same for all frequencies is verified.

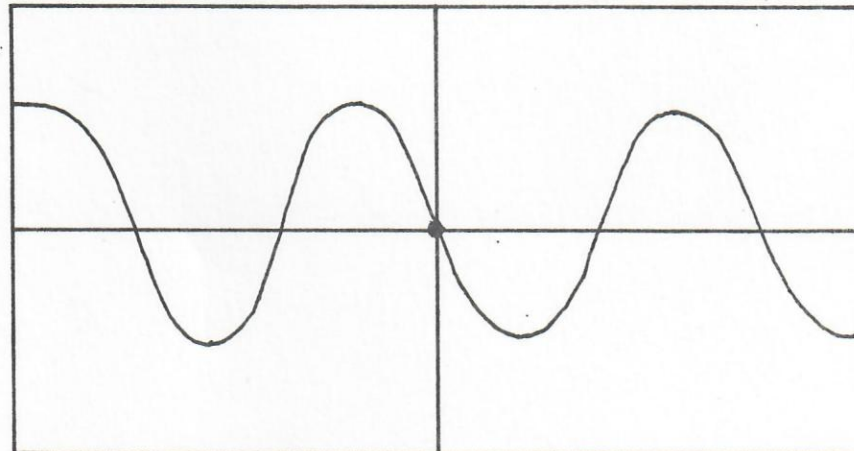
In measuring the A.C. voltages, the oscilloscope can be used to measure the peak to peak voltage and the A.C. meter can be read in peak to peak or in RMS voltage, depending on the scale used. Note that when applying the voltage divider formula V_{in} and V_{out} must both be in either peak to peak or RMS.

Note that when measuring the output for different frequencies the input voltage must be carefully adjusted to 5 volts for each different frequency. This must be done, because, as the signal generator frequency is adjusted, the amplitude of the signal generator will also change.

4. Output Voltage

$$V_{out} \text{ (pk-to-pk)} = 3.3\text{Kvolts}$$

5. Recorded Voltage Output



6. Tabulation of peak to peak output voltage for various frequency signals.

set frequency	SWITCH A, UP	SWITCH A, DOWN
	SET INPUT V_{IN} (pk to pk)	READ V_{OUT} (pk to pk)
200 Hz	5	3.3
1 KHz	5	3.3
5 KHz	5	3.3
10 KHz	5	3.3
15 KHz	5	3.3
20 KHz	5	3.3

OSCILLOSCOPE AND SINE-WAVES

QUESTIONS:

1. Does the resistance voltage divider operate the same for all frequencies tested?

Yes, the voltage divider ratio is the same for all frequencies.

2. What would the output voltage read for an input voltage of 4 volts and a frequency of 12KHz?

Since the circuit is resistive, the normal voltage divider ratio is used.

$$V_{out} \text{ (pk to pk)} = \frac{V_{in} \text{ (pk to pk)}(2.2K)}{2.2K + 1K} = \frac{4(2.2)}{3.2} = 2.66 \text{ volts}$$



Frequency	Input Voltage (pk to pk)	Output Voltage (pk to pk)
200 Hz	4	2.5
1 KHz	4	2.5
5 KHz	4	2.5
10 KHz	4	2.5
12 KHz	4	2.5
20 KHz	4	2.5

SERIES R-L AND INDUCTIVE REACTANCE

The voltage and current in an inductance is measured for various frequencies. The inductive reactance as a function of frequency is determined.

4. Tabulation of Voltage, Current and Reactance for 50 mhy inductor

set frequency	(pk to pk) set input V_{IN}	read V_L	read V_R	calculate $I = \frac{V_R}{R}$	calculate $X_L = \frac{V_L}{I}$
200 Hz	5	0.43	4.7	4.7 ma	91 ohms
1 KHz	5	1.40	4.5	4.5 ma	311 ohms
3 KHz	5	3.3	3.4	3.4 ma	920 ohms
5 KHz	5	4.2	2.45	2.45 ma	1714 ohms
10 KHz	5	4.8	1.4	1.4 ma	3428 ohms
15 KHz	5	4.9	0.9	0.9 ma	5.444 ohms
20 KHz	5	4.95	0.6	0.6 ma	8250 ohms

5. Example of calculation of Inductor Current

After entering the data for V_L and V_R

Calculate I:

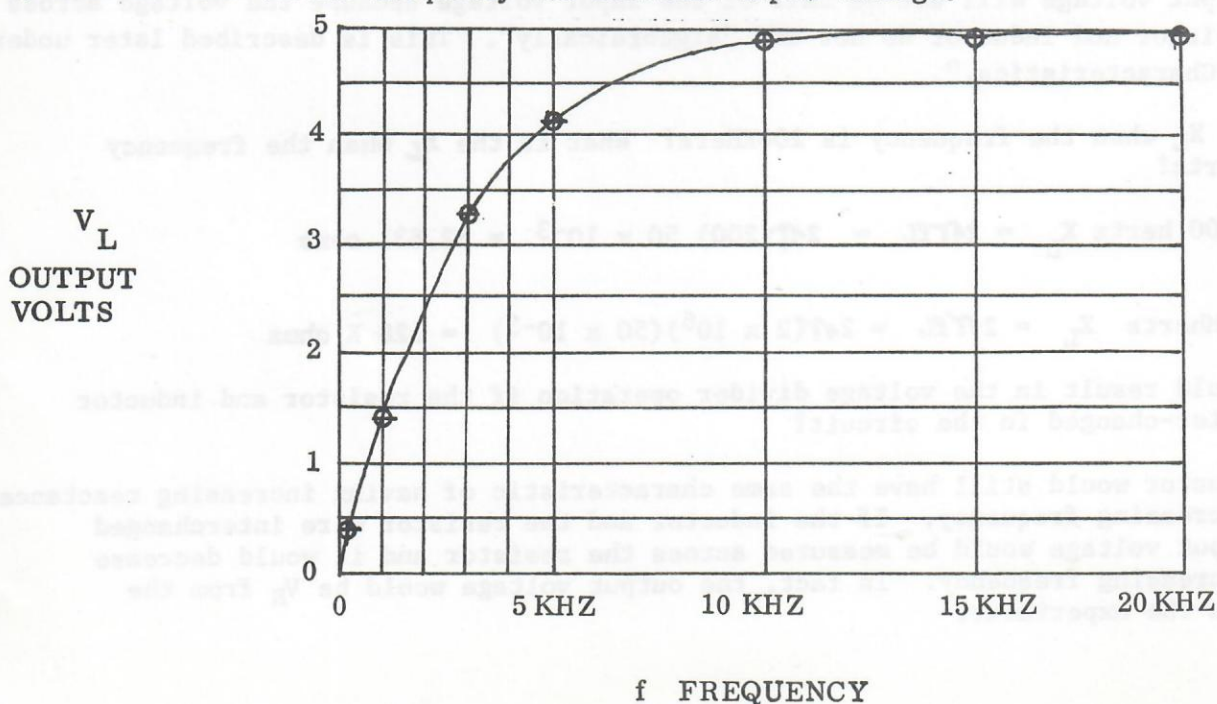
$$I = \frac{V_R}{R} \quad \text{where } R = 1K = 1,000 \text{ OHMS}$$

Thus "I" is just V_R in milliamps

Example: If $V_R = 4.2$ volts

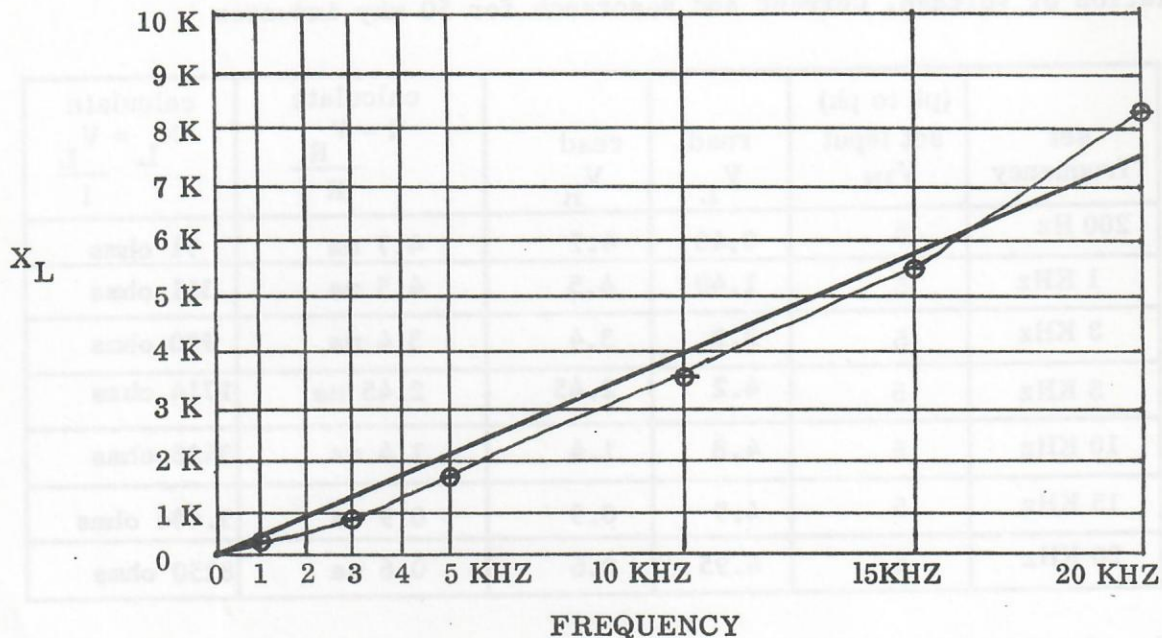
Then $I = 4.2$ ma.

7. Plot of V_{out} versus frequency for constant input voltage.



SERIES R-L AND INDUCTIVE REACTANCE

9. Graph showing measured and theoretical inductance are in close agreement.



QUESTIONS:

1. When X_L is equal to 1K (Same value as the resistor) the voltage across the inductor is equal to the voltage across the resistor. At what frequency is X_L equal to 1K? Is the output voltage half of the input voltage at this frequency? (Note: This question has been changed in later editions of the Lab Manuals.)

$$X_L = 2\pi fL \rightarrow f = \frac{X_L}{2\pi L} = \frac{10^3}{2\pi 50 \times 10^{-3}} = 2,183 \text{ hertz}$$

The output voltage will not be half of the input voltage because the voltage across the resistor and inductor do not add "algebraically". This is described later under "Phase Characteristics."

2. What is X_L when the frequency is 200KHz? What is the X_L when the frequency is 2Mhertz?

$$200 \text{ hertz } X_L = 2\pi fL = 2\pi(200) 50 \times 10^{-3} = 62.831 \text{ ohms}$$

$$2\text{Mhertz } X_L = 2\pi fL = 2\pi(2 \times 10^6)(50 \times 10^{-3}) = 628 \text{ K ohms}$$

3. What would result in the voltage divider operation if the resistor and inductor were inter-changed in the circuit?

The inductor would still have the same characteristic of having increasing reactance with increasing frequency. If the inductor and the resistor were interchanged the output voltage would be measured across the resistor and it would decrease with increasing frequency. In fact, the output voltage would be V_R from the table in the experiment.

SERIES R-C AND CAPACITIVE REACTANCE

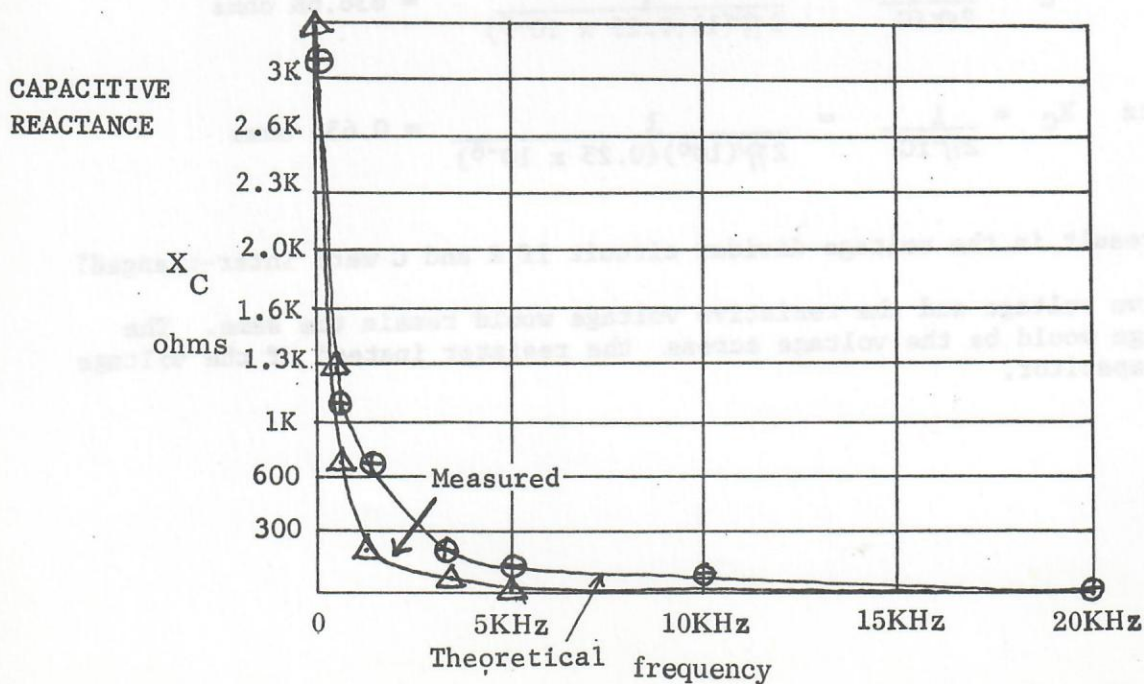
Capacitance voltage and current is measured for various frequencies and Capacitive Reactance is calculated. These measurements are compared with theoretical values.

3. Tabulation of Voltages for various input frequencies. Note that the amplitude of the input voltage must be adjusted to 5 volts for each frequency.

All Voltages: Peak to Peak

set	adjust	measure		calculate from data		theoretical
frequency	V_{in}	V_R	V_C	$I_C = \frac{V_R}{1K}$	$X_C = \frac{V_C}{I_C}$	$X_C = \frac{1}{2\pi fC}$
200 Hz	5	1.45	4.8	1.45 ma	3.3K	3.183K
500 Hz	5	3.0	4.0	3.0 ma	1.33K	1.27K
1KHz	5	4.1	2.6	4.1 ma	634 ohms	636
3KHz	5	4.8	1.0	4.8 ma	208 ohms	212 ohms
5KHz	5	4.9	.6	4.9 ma	122 ohms	127 ohms
10KHz	5	5.0	0.3	5.0 ma	60 ohms	63
20KHz	5	5.0	0.1	5.9 ma	20 ohms	31

6. Graph of measured and theoretical values of X_C versus frequency.



SERIES R-C AND CAPACITIVE REACTANCE

7. Calculation of Susceptance at 1KHz.

$$S_C = 2 \pi f C$$

for 1KHz .

0.25 mfd

$$S_C = 6.37 \times 10^{-4} \text{ MHO}$$

QUESTIONS:

1. When X_C is equal to the resistance (1K), the output voltage should be half. At what frequency is X_C equal to 1000 ohms? Is the output voltage equal to half the input voltage at this frequency? Note: The output voltage will not be half the input because the voltages across the capacitor and resistor are out of phase. This is discussed in a later experiment. Later editions of the Lab Manual do not state this question in this way.

$$X_C = \frac{1}{2 \pi f C}$$

$$f = \frac{1}{2 \pi X_C} = \frac{1}{2 (1000) (0.25 \times 10^{-6})} = 636 \text{ Hertz}$$

At 636 Hertz the output voltage is 3.5volts.

2. What is X_C at 1 Hertz? What is X_C at 1 Megahertz?

$$1 \text{ Hertz} \quad X_C = \frac{1}{2 \pi f C} = \frac{1}{2 \pi (1) (0.25 \times 10^{-6})} = 636.6 \text{K ohms}$$

$$1 \text{ M Hertz} \quad X_C = \frac{1}{2 \pi f C} = \frac{1}{2 \pi (10^6) (0.25 \times 10^{-6})} = 0.636 \text{ ohms}$$

3. What would result in the voltage divider circuit if R and C were inter-changed?

The capacitive voltage and the resistive voltage would remain the same. The output voltage would be the voltage across the resistor instead of the voltage across the capacitor.

R-L-C CIRCUITS FREQUENCY RESPONSE

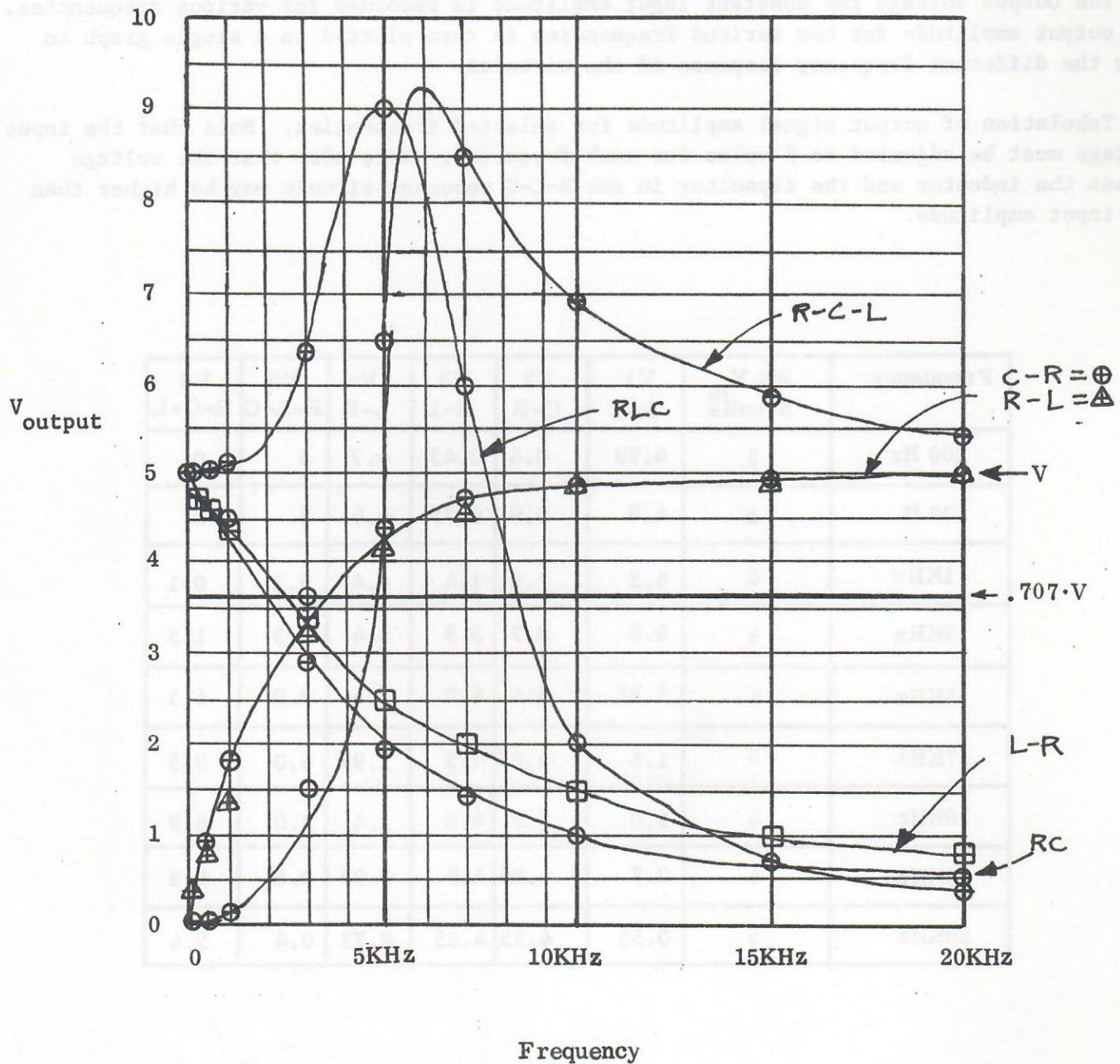
The frequency response of several circuits are recorded and plotted. This serves as the introduction to High Pass, Low Pass and Tuned Circuits. Six separate circuits using Resistors, Capacitors and Inductors are shown. Each is driven by the Audio Oscillator and the Output voltage for constant input amplitude is recorded for various frequencies. The output amplitude for the various frequencies is then plotted on a single graph to show the different frequency response of the circuits.

1. Tabulation of output signal amplitude for selected frequencies, Note that the input voltage must be adjusted to 5 volts for each frequency. Note also that the voltage across the inductor and the capacitor in the R-L-C resonant circuit may be higher than the input amplitude.

Frequency	Set V _{in} 5 volts	V1 R-C	V2 C-R	V3 R-L	V4 L-R	V5 R-L-C	V6 R-C-L
200 Hz	5	4.99	0.4	0.43	4.7	5	0
500 H	5	4.8	0.9	0.75	4.6	5	0
1KHz	5	4.5	1.8	1.4	4.4	5.1	0.1
3KHz	5	2.9	3.7	3.3	3.4	6.3	1.5
5KHz	5	1.95	4.4	4.2	2.5	9.0	6.5
7KHz	5	1.4	4.65	4.5	1.95	6.0	8.5
10KHz	5	1.0	4.8	4.8	1.4	2.0	6.9
15KHz	5	0.7	4.85	4.9	0.95	0.8	5.8
20KHz	5	0.55	4.95	4.95	0.72	0.4	5.4

R-L-C CIRCUITS FREQUENCY RESPONSE

2. Graph of the frequency response for the circuits.



QUESTIONS:

- Describe the operation of each of the circuit configurations in this experiment. Indicate whether each one is a LOW Frequency Pass Filter (LOW PASS FILTER) or a HIGH PASS FILTER?

Fig. 4-1 is a LOW PASS Circuit. For low frequencies the capacitive reactance is

R-L-C CIRCUITS FREQUENCY RESPONSE

very high and the input voltage will appear at the output with very little attenuation. At high frequencies the reactance of the capacitor is low and the output voltage will be small. The circuit is said to PASS the LOW frequencies.

Figure 4-2 is a HIGH PASS Circuit. The capacitive reactance is high for low frequencies and the capacitor will block the voltage to the output making the output low. At high frequencies the capacitor is a very low impedance and the output amplitude will be high.

Fig. 4-3 This R-L circuit is a high pass circuit because the inductive reactance increases with increasing frequency.

Fig. 4-4 A low pass circuit where increasing inductive reactance causes the the output to decrease with increasing frequency.

Fig. 4-5 and 4-6 These are resonant R-L-C circuits and the output amplitude will be a maximum for the resonant frequency of the circuit.

2. For a resistive output load, the load power (P_L) is:

$$P_L = \frac{V_{out}^2}{R}$$

Half of this Power is $\left(\frac{P_L}{2}\right)$ and this occurs at a voltage output of

$$\left(V_{out} \text{ at } \frac{1}{2} \text{ POWER}\right) = \frac{V_{out}}{2} = .707 V_{out}$$

The 0.707 voltage for a 5 volt output corresponds to 3.54 volts and is indicated on the graph as a dark line. This half-power output is called the CUT-OFF FREQUENCY and the FILTER Circuit.

Using the graph, what is the CUT-OFF FREQUENCY for each FILTER?

FILTER CIRCUIT	CUT-OFF FREQUENCY
Fig. 4-1 R - C	2KHz
Fig. 4-2 C - R	3.1KHz
Fig. 4-3 R - L	3.2KHz
Fig. 4-4 L - R	2.5KHz
Fig. 4-5 L - C	3.5 - 6.5KHz
Fig. 4-6 C - L	5 - 10KHz

LOW SPEED R-C TIME CONSTANT

The rise in capacitance voltage versus time for a step D.C. voltage is measured. The discharge rate of the charged capacitor will also be measured. The voltage source V2, or ground can be switched to the 100K, 100 ufd series circuit. When V2 is connected to the 100K resistor, current will flow and the capacitors will charge up towards V2. During this charging time the time and voltage across the capacitor will be recorded and graphed. After the capacitor is charged, if the circuit is connected to ground with the switch, the capacitor will discharge and the decrease of capacitor voltage with time is recorded and graphed.

3. Record of the capacitor voltage versus time.

DATA TABLE I CHARGE

V _{out}	time seconds
0	0
1	3
2	4.5
3	6
4	9.5
5	13
6	17.5
7	24
8	34
9	62
V _{max} =	120

DATA TABLE II DISCHARGE

V _{out}	time seconds
V _{max} =	0
9	1
8	3
7	5
6	8
5	11
4	15
3	19
2	25
1	37
0	140

4. Record of Maximum Voltage.

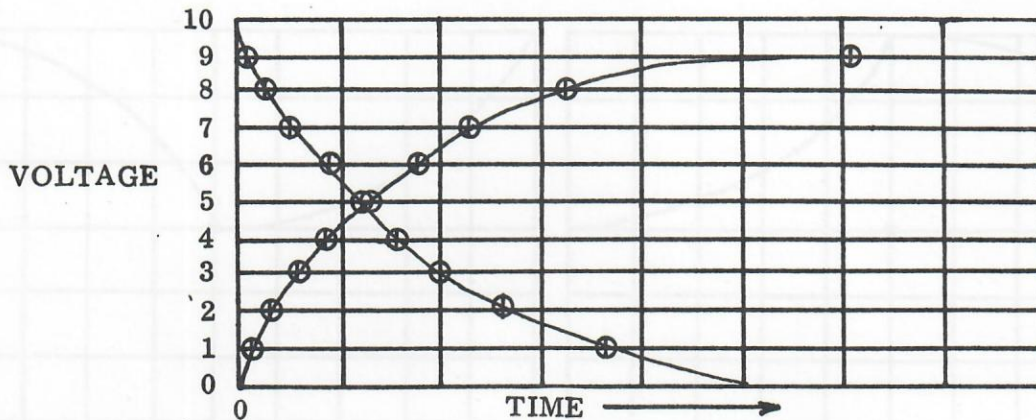
V_{max} = 9.3 volts

5. Record of discharge rate. See table II.

LOW SPEED R-C TIME CONSTANT

CALCULATIONS:

1. Plot of charge and discharge rate.



3. Measurement of 63% point for "one time constant" charge time.

$$V_1 = 5.86 \text{ volts}$$

$$\tau(\text{graph}) = 9.5 \text{ sec}$$

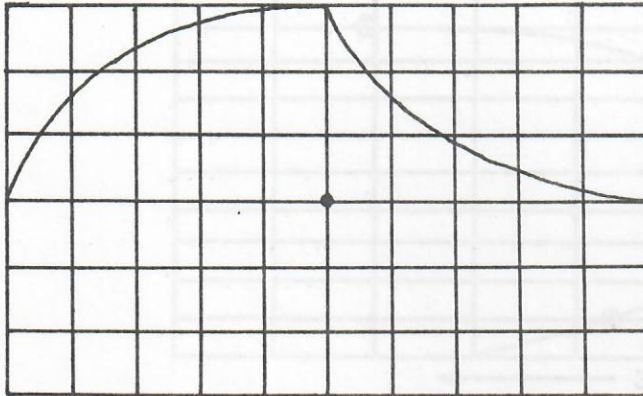
4. How does this measured value of "T" from the graph compare with the theoretical calculation of "T" = 10 seconds?

The measured and theoretical values are within 0.5 sec which is 5%.

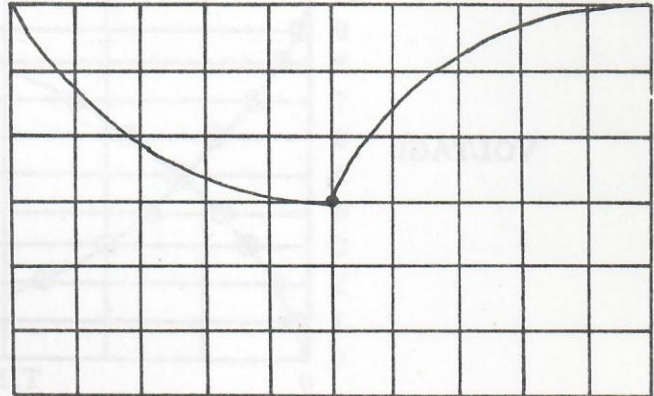
R-C TIME CONSTANT - DYNAMIC MEASUREMENT

The Time Constant of R-C networks is measured using a square wave signal generator to repetitively charge and discharge the network.

6. Sketch of the output waveform



SCOPE (+SYNCH.)



SCOPE (-SYNCH.)

8. Measurement of the circuit Time Constant

The time for the charging curve to reach 63% of full voltage and the discharging curve to reach 37% of full voltage will be the time constant of the circuit.

Time Constant = τ = 1.3 milliseconds

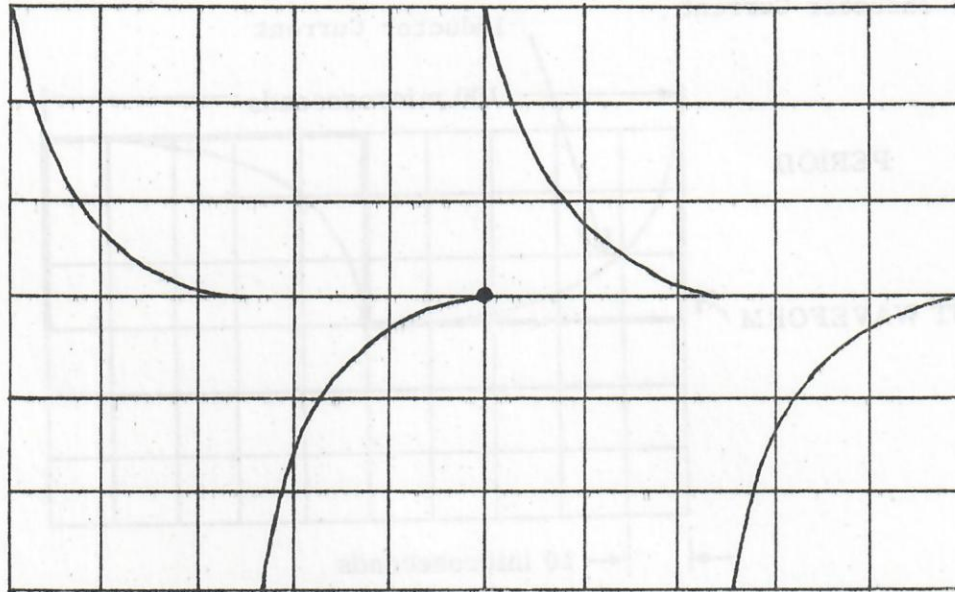
9. Calculation of Theoretical Time Constant

Theoretical τ = R-C
 where R = 100,000 ohms
 $C = 0.01 \times 10^{-6}$ farads
 and τ = seconds

Theoretical $\tau = 10^5 \times 10^{-8} = 10^{-3} = 1 \text{ millisecon}$

R-C TIME CONSTANT - DYNAMIC MEASUREMENT

12. Measurement of Circuit Current

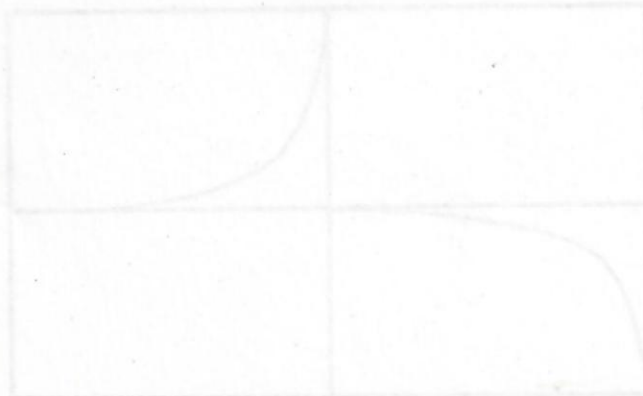


SCOPE (+ SYNCH.)

13. What do the above current waveforms and the previous voltage waveforms show?

The voltage curve shows that the capacitor will slowly charge toward the supply voltage in a resistor - capacitor network and that the capacitor voltage will approach the final supply voltage with a particular shape curve. When a charged capacitor discharges through a resistor the voltage will have a similar time curve to the charging curve, but downward in direction.

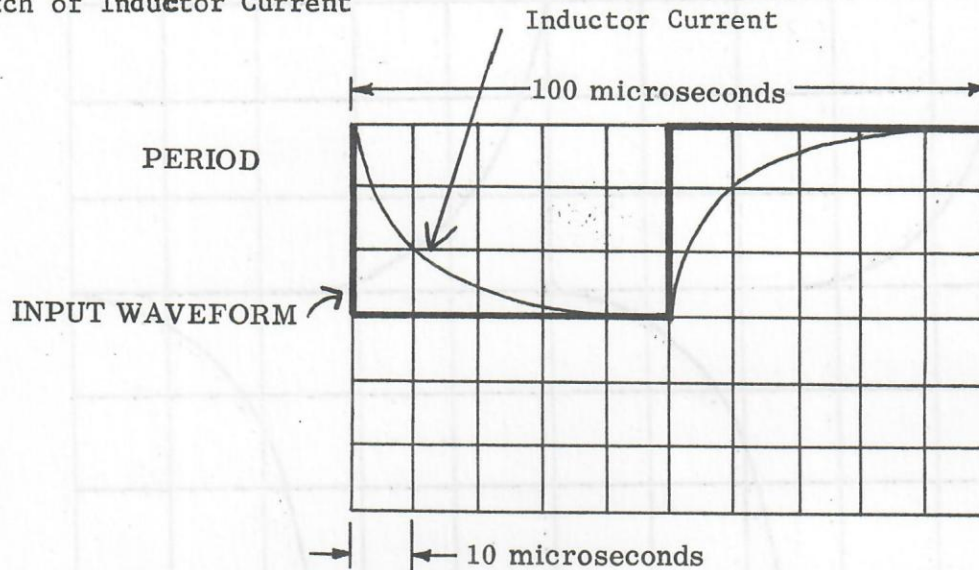
The current curve shows that the circuit initially conducts a high current, but as the voltage across the capacitor approaches the source voltage the current decreases. When the capacitor is charge fully, the current through the capacitor is zero.



R-L TIME CONSTANT - DYNAMIC MEASUREMENT

The time constant in a R-L series circuit is measured. The output voltage across the inductor is measured and recorded.

5. Sketch of Inductor Current



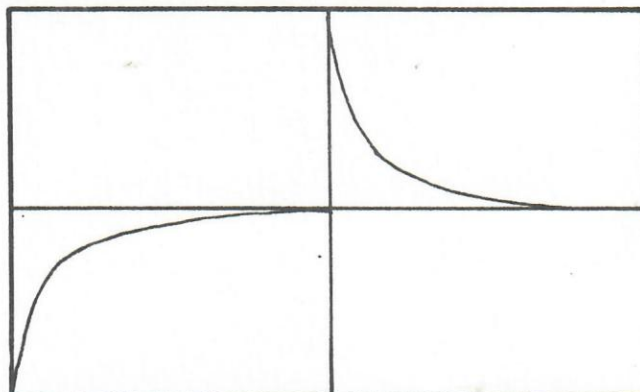
6. Measurement of Time Constant. The time constant is measured as the length of time required for the Inductor Current to reach 63% of its full value measured from the edge of the positive going input pulse.

Estimated $\tau = 10 \mu \text{ sec}$

7. How does this measured value compare with the theoretical Time Constant?

The calculated and measured Time Constant are both 10 microseconds.

8. Measurement of Inductor Voltage



R-L TIME CONSTANT - DYNAMIC MEASUREMENT

9. Comment on the Inductor Voltage "Polarity".

The inductor voltage is positive for increasing inductor current and negative for decreasing inductor current. The voltage across an inductor is given by:

$$V = L \frac{di}{dt} \quad \text{where } \frac{di}{dt} \text{ is the derivative of the current with respect to time.}$$

another way to state this is:

$$V = L (\text{Slope of the inductor current})$$

10. Calculate the Inductive Time Constants (T) for the following:

a. $R = 1K \quad L = 50 \text{ mhy} \quad T = \frac{L}{R} = \frac{50 \times 10^{-3}}{10^3} = 50 \times 10^{-6} = 50 \text{ u sec}$

b. $R = 100K \quad L = 25 \text{ mhy} \quad T = \frac{L}{R} = \frac{25 \times 10^{-3}}{100 \times 10^3} = 0.25 \times 10^{-6} = 250 \text{ n sec}$

c. $R = 0 \quad L = 10\text{mhy} \quad T = \frac{L}{R} = \frac{10 \times 10^{-3}}{0} = \infty \text{ (infinity)}$

INDUCTORS IN SERIES

The rule that the inductances of inductors connected in series must be added to obtain the overall circuit inductance is verified.

4. Tabulation of the circuit voltages and the calculation of the inductive reactance for both inductors in series and the 50 mhy inductor alone.

Measure the voltages and enter them in the table. Then calculate X_L for $L = 75$ mhy and for $L=50$ mhy.

	SET	MEASURE		CALCULATE
	V_{in}	V_R	V_L	$X_L = \frac{V_L}{V_R} \text{ K OHMS}$
L = 75 mhy SERIES (50+25)	5V	1.72	2.9	$X_L = \frac{2.9}{1.72} = 1.69K$
L = 50 mhy	5V	.2	2.1	$X_L = \frac{2.1}{2.2} = 0.954K$

How do these results compare with the theoretical results? Do these experimental results verify that series inductors ADD?

For the 75 mhy inductor the error is:

$$\% \text{ Error} = \frac{1.69 - 1.41}{1.41} \times 100 = \frac{0.28}{1.41} \times 100 = 19.8\%$$

For the 50 mhy inductor the error is:

$$\% \text{ Error} = \frac{954 - 942}{942} \times 100 = \frac{12}{942} = 1.27\%$$

INDUCTORS IN PARALLEL

Two Inductors are connected in parallel and the inductive reactance of this combination is measured. The experiment results will be compared with the calculated results.

3. Tabulation of V_R and V_L and X_L .

	SET	MEASURE		CALCULATE
	V_{in}	V_R	V_L	$X_L = \frac{V_L}{V_R} \text{ KILOHMS}$
PARALLEL L (50 mhy) (25 mhy)	5V	4.6volts	1.45	.315 kilohms

4. Do the results verify the operation of parallel inductors? Yes the results are within 3% of the calculated inductive reactance.

QUESTIONS:

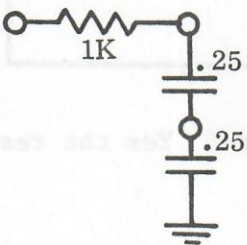
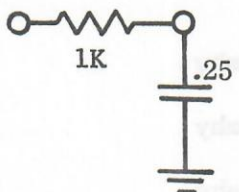
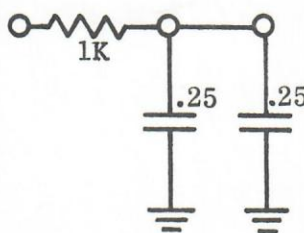
1. What is the inductance of the following combinations of inductors?

- | | | |
|--------------|-------------------------|---------|
| a. SERIES; | 10 mhy, 25 mhy? | 35 mhy |
| b. SERIES; | 10 mhy, 25 mhy, 75 mhy? | 110 mhy |
| c. SERIES; | 1 mhy, 100 mhy? | 101 mhy |
| d. PARALLEL; | 1 mhy, 100 mhy? | 1 mhy |
| e. PARALLEL; | 10 mhy, 10 mhy? | 5 mhy |

CAPACITORS IN SERIES AND PARALLEL

The experiment will verify the formulas for the total capacitance of two capacitors in series and in parallel by showing that the Capacitive Reactance of two equal capacitors in series is twice the capacitive reactance for a single capacitor and that the Capacitive Reactance for two equal capacitors in Parallel is equal to HALF the capacitive reactance of a single capacitor. Since capacitive reactance is proportional to the inverse of capacitance, TWICE the reactance indicates HALF the capacitance.

2. Tabulated Results

	SET	READ		CALCULATE
	V_{in}	V_R	V_C	$X_C = \frac{V_C}{V_R} \text{ KILOHMS}$
SERIES CAPS 	5V.	4.6 V	1.85 V	$\frac{1.85}{4.6} \times 1000 =$ 402 ohms
ONE CAP 	5V.	4.85	1.0 V	$\frac{1.0}{4.85} \times 1000 =$ 206 ohms
PARALLEL CAPS 	5V.	5.0 V	0.5 V	$\frac{.5}{5} \times 1000 =$ 100 ohms

CAPACITORS IN SERIES AND PARALLEL

3. Do the results verify the operation of SERIES and PARALLEL Capacitors?

The calculated results from experimentation agree very closely with the theoretical results.

QUESTIONS:

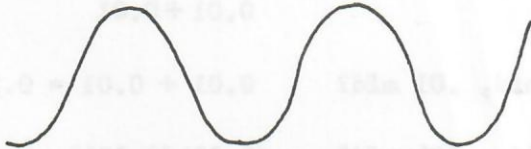
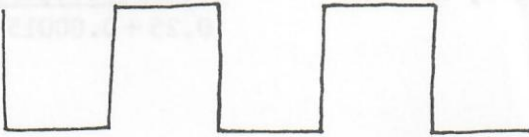
1. What are the resultant capacitances?

- | | |
|---------------------------------|--|
| a) SERIES; .01 mfd, .01 mfd? | $\frac{(0.01)(0.01)}{0.01 + 0.01} = 0.05 \text{ mfd}$ |
| b) PARALLEL; .01 mfd, .01 mfd? | $0.01 + 0.01 = 0.2 \text{ mfd}$ |
| c) SERIES: .25 mfd, .001 mfd? | $\frac{(0.25)(0.001)}{0.25 + 0.001} = \frac{0.00025}{0.251} = 0.001 \text{ mfd}$ |
| d) PARALLEL; .25 mfd, .001 mfd? | $0.25 + 0.001 = 0.251$ |
| e) PARALLEL; .7 mfd, .3 mfd? | $0.7 + 0.3 = 1.0 \text{ mfd}$ |
| f) SERIES; .25 mfd, 150 pfd | $\frac{(0.25)(0.00015)}{0.25 + 0.00015} = 150 \text{ pfd (picofarads)}$ |

LISSAJOUS PATTERNS

Two Sine Wave Signal Generators are connected to an oscilloscope, one to the vertical and one to the horizontal amplifier. The pattern on the oscilloscope will be elliptical trace called a Lissajous Pattern. This pattern will be used to adjust the frequency of the two generators to the same frequency and to adjust them to various harmonics of each other. This frequency matching will be used to calibrate the Ed-Lab 650 Signal Generator against the External Audio Generator.

3. When the 1K POT is varied, the frequency of the output signal will be seen to change. Wave forms of Ed-Lab Signal Generator Outputs are shown below:

SINE	
TRIANGLE	
SQUARE	

5. The External Generator frequency is adjusted to match the Ed-Lab 650 Signal Generator. This point is determined by observing an elliptical trace of the oscilloscope. Note that the trace may revolve or flop around due to phase changes between the two signals.

VOLTAGE (at f) =	4.0 volts
FREQUENCY =	10.09 KHz

6. The 1K frequency control POT is adjusted to the readings indicated in the left hand column of the table below. The external sine wave generator is then adjusted for an elliptical pattern, which indicates that the external audio generator is set at the same frequency as the Ed-Lab generator. The frequency is recorded.

LISSAJOUS PATTERNS

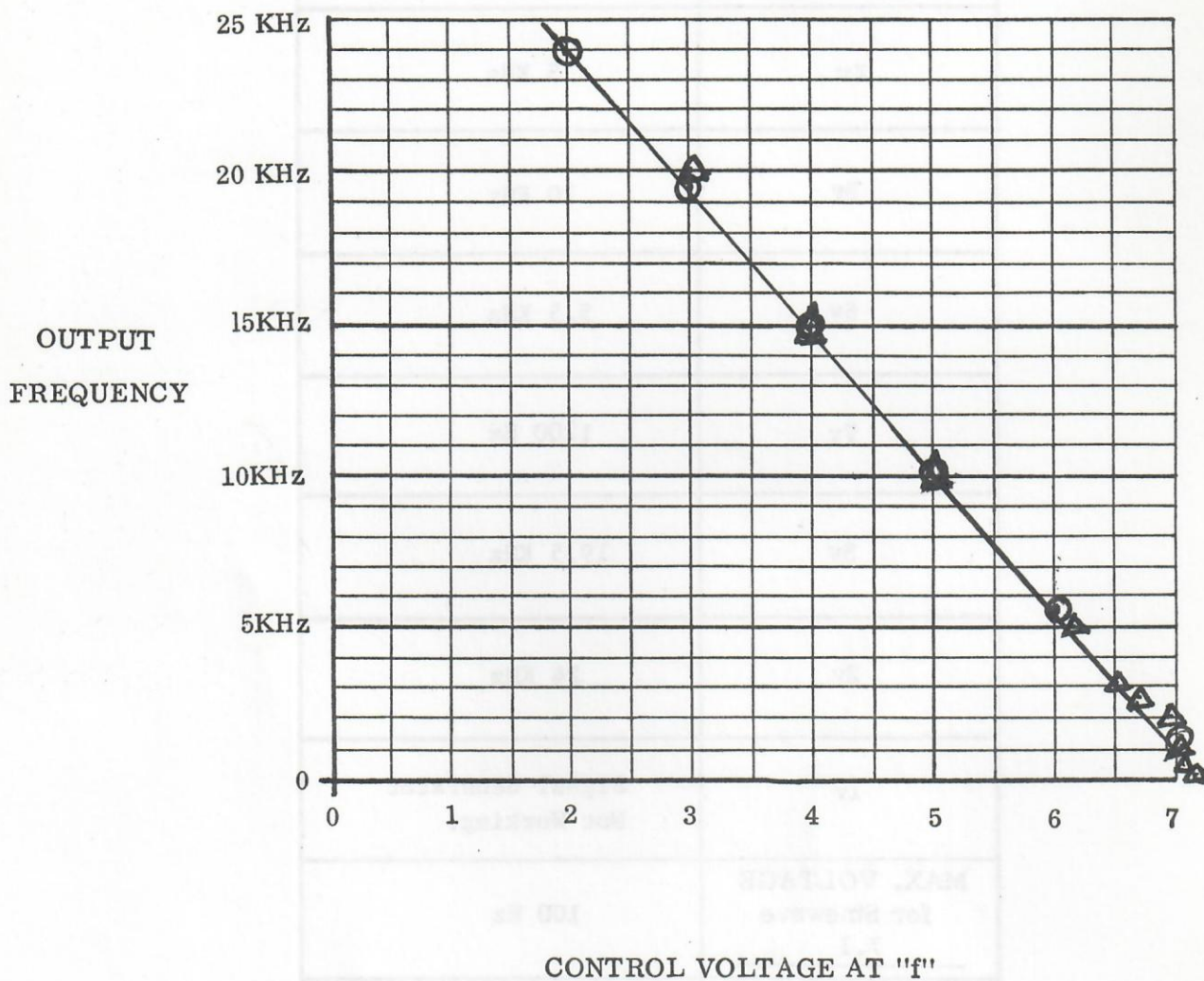
SET 1K POT	ADJUST EXT. GENERATOR
VOLTAGE	FREQUENCY
4v	15 KHz
5v	10 KHz
6v	5.5 KHz
7v	1200 Hz
3v	19.5 KHz
2v	24 KHz
1v	Signal Generator Not Working.
MAX. VOLTAGE for Sinewave 7.1	100 Hz
MIN. VOLTAGE for Sinewave 1.6	25 KHz

7. Record of Maximum and Minimum Control Voltages and frequencies for the Ed-Lab Signal Generator.

CONTROL VOLTAGE	FREQUENCY
MAXIMUM = 7.1	100 Hz
MINIMUM = 1.6	25 KHz

LISSAJOUS PATTERNS

8. Graph of the Control Voltage versus Frequency for the Ed-Lab Signal Generator.



RECORD OF MAXIMUM AND MINIMUM CONTROL VOLTAGES AND FREQUENCIES FOR THE ED-LAB SIGNAL GENERATOR.	
FREQUENCY	
100 Hz	MAXIMUM = 7.1
25 KHz	MINIMUM = 1.5

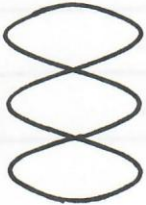
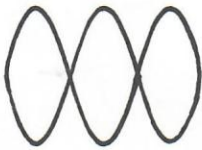
LISSAJOUS PATTERNS

9. The External Signal Generator is set to a particular frequency and the 1K POT is adjusted to match the Ed-Lab 650 frequency to the External Signal Generator Frequency. These points are plotted on the graph.

FREQUENCY	CONTROL VOLTAGE 1K POT to "f"
200 Hz	7.3
500 Hz	7.1
1 KHz	7.05
2KHz	6.9
2.5 KHz	6.7
3 KHz	6.5
5 KHz	6.0
10 KHz	5.0 v
15 KHz	4.0 v
20 KHz	3.0 v

LISSAJOUS PATTERNS

10.

SET	ADJUST	ADJUST External Sine Generator	CHECK Pattern
Ed-Lab Signal Generator	External Sinewave Generator	Oscilloscope Pattern	Actual External Frequency
5 KC	5 KHz		4.95 KHz
5KC	10 KHz		10 KHz
5KC	15 KHz		14.9 KHz
5KC	2.5 KHz		2.48 KHz
5KC	1.25 KHz		1.22 KHz

CAPACITANCE PHASE CHARACTERISTICS

A Lissajous Pattern is used to measure the Phase Shift caused by the circuit in a series R-C network.

The 0.01 microfarad capacitor and the 10K resistor are connected in series to form a series R-C circuit. The vertical input to the oscilloscope is connected to the input voltage into the series circuit. The horizontal input to the oscilloscope is connected across the 10K resistor, which means that the horizontal input is proportional to the Circuit Current.

$$i = \frac{e}{R} = \frac{e}{10K}$$

The Vector Diagram of impedance is given in the body of the experiment and will not be repeated here. The Lissajous Pattern is used to measure the phase difference between the vertical and horizontal channels on the oscilloscope.

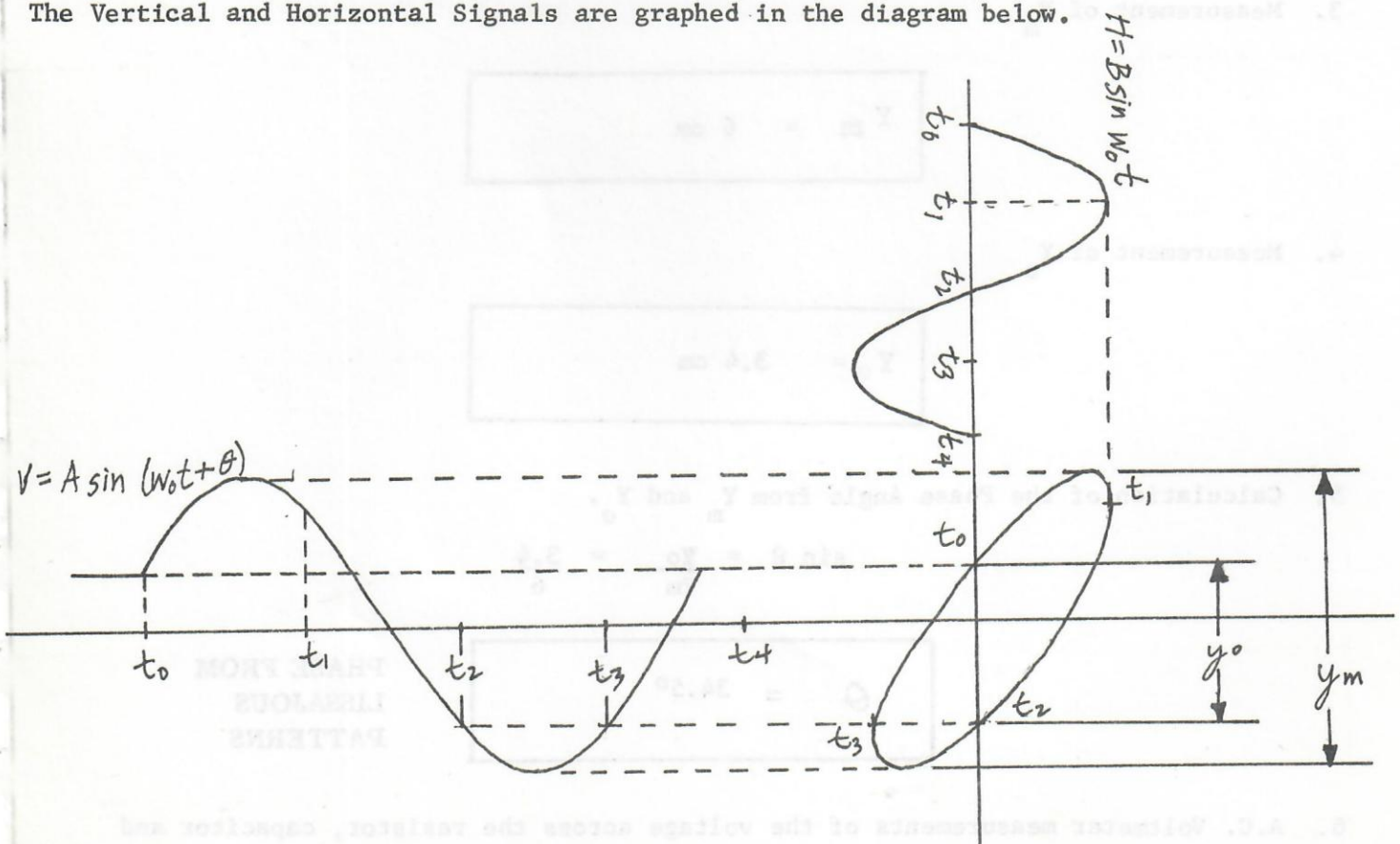
Suppose the vertical channel has the signal input

$$V = A \sin (\omega_0 t + \theta)$$

and the horizontal channel has the signal input

$$H = B \sin (\omega_0 t)$$

The Vertical and Horizontal Signals are graphed in the diagram below.



CAPACITIVE PHASE CHARACTERISTICS

Y_m = Maximum Vertical Amplitude of the Lissajou Pattern

$Y_m = 2A$, (Twice the Amplitude of the Vertical Signal)

Y_o = The Vertical Amplitude of the Lissajou Pattern

$Y_o = 2A \sin(\omega_o t + \theta)$ when $B \sin \omega_o t = 0$

$B \sin \omega_o t = 0$ when $\omega_o t = 0$

therefore

$Y_o = 2A \sin \theta$

$$\sin \theta = \frac{Y_o}{Y_m} = \frac{2A \sin \theta}{2A}$$

$$\theta = \sin^{-1} \left(\frac{Y_o}{Y_m} \right)$$

The Phase Angle between the two inputs is the arc sine of $\frac{Y_o}{Y_m}$.

3. Measurement of Y_m

$$Y_m = 6 \text{ cm}$$

4. Measurement of Y_o

$$Y_o = 3.4 \text{ cm}$$

5. Calculation of the Phase Angle from Y_m and Y_o .

$$\sin \theta = \frac{Y_o}{Y_m} = \frac{3.4}{6}$$

$$\theta = 34.5^\circ$$

PHASE FROM
LISSAJOUS
PATTERNS

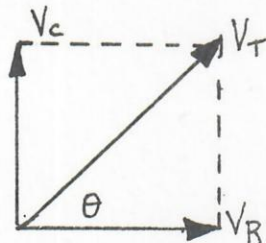
6. A.C. Voltmeter measurements of the voltage across the resistor, capacitor and the input.

CAPACITANCE PHASE CHARACTERISTICS

A.C. V_R	=	10 VRMS
A.C. V_C	=	8 VRMS
A.C. V_{in}	=	13 VRMS

7. Calculation of V_{in} from the V_R and V_C measured in step 6.

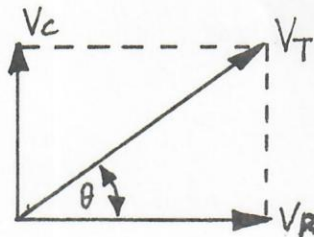
Since the Capacitive Voltage and the Resistor Voltage are in quadrature, or oriented at 90° to each other on the Vector Diagram, the sum or resultant voltage which is equal to the input voltage can be calculated using Pythagoras Theorem



$$V_T = 12.8$$

$$V_T = \sqrt{V_R^2 + V_C^2} = \sqrt{10^2 + 8^2} = \sqrt{164} = 12.8 \text{ VRMS}$$

8. Calculation of the Phase Angle from the Voltages Measured in step 6.



$$\tan \theta = \frac{V_C}{V_R}$$

$$\tan \theta = \frac{8}{10}$$

$$\theta = 38.6$$

9. Calculation of Phase Angle from Impedance Formula

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi (2 \times 10^3)(0.01 \times 10^{-6})} = 7.957 \text{ K}$$

$$R = 10 \text{ K}$$

$$\tan \theta = \frac{X_C}{R} = \frac{7.9}{10} = 38.5^\circ$$

$$X_C = 7.957 \text{ K OHMS}$$

$$\theta = 38.51^\circ$$

CAPACITIVE PHASE CHARACTERISTICS

Compare the Phase Angle calculated by:

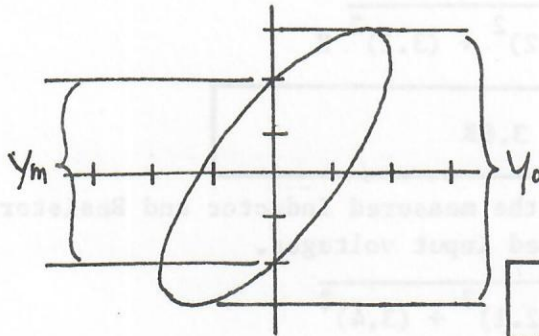
- θ from IMPEDANCES.....38.5.....
- θ from VOLTAGES.....38.6.....
- θ from LISSAJOUS PATTERNS.....34.5.....

All the methods of calculating the Phase Angle agree to within 12%

INDUCTIVE PHASE CHARACTERISTICS

The circuit voltages and the Phase Angle between Input Voltage and Circuit Current for a Series R-L circuit is measured. This is the introduction to the measurement of Impedance and the concept of Phase Angle in Reactive Components.

3. Measurement of Y_o and Y_m of the Lissajou Pattern.



Y_m	=	6
Y_o	=	5

center
pattern

4. Measurement of A.C. Voltages at the Input and across the Inductor and the Resistor using the A.C. Voltmeter.

A.C. V_{in}	=	4 VRMS
A.C. V_R	=	2.1 VRMS
A.C. V_L	=	3.4 VRMS

5. Calculation of Phase Angle

Lissajous Pattern	$\sin \theta = \frac{Y_o}{Y_m} = 0.833$	$\theta = 56.4^\circ$
Voltage Measurement	$\tan \theta = \frac{V_L}{V_R} = 1.619$	$\theta = 58.3^\circ$
Impedance Calculation	$X_L = 2 \pi f L$ $X_L = 2 \pi (10 \cdot 10^3) (50 \cdot 10^{-3})$ $X_L = 3.142K$ $R = 2.2K$ $\tan \theta = \frac{X_L}{R} = 1.43$	$\theta = 55^\circ$

INDUCTIVE PHASE CHARACTERISTICS

The measurements and theoretical calculation are in very close agreement.

6. Impedance Calculation of the Series Circuit is the Vector sum of the Impedances of the Inductor and the Resistor. Since the Inductor Impedance is 90° out of Phase with the Resistance the total Impedance can be found by using Pythagoras' Theorem.

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{(2.2)^2 + (3.1)^2} \text{ K}$$

$$Z = 3.8 \text{ K}$$

7. Calculation of the Input Voltage from the measured Inductor and Resistor Voltages. The result is compared with the measured input voltages.

$$V_T = \sqrt{V_R^2 + V_L^2} = \sqrt{(2.1)^2 + (3.4)^2}$$

$$V_T = 3.996$$

The Error is:

$$\% \text{ Error} = \frac{4.0 - 3.996}{4.0} \times 100 = \frac{(0.004)}{4.0} \times 100 = 0.1\%$$

Impedance Calculation	$X_L = 2\pi fL$ $X_L = 2\pi (60)(0.01)$ $X_L = 3.77 \text{ K}$ $R = 2.2 \text{ K}$ $\tan \theta = \frac{X_L}{R}$ $\tan \theta = \frac{3.77}{2.2}$ $\theta = 59.5^\circ$	Impedance
Voltage Measurement	$\tan \theta = \frac{V_L}{V_R}$ $\tan \theta = \frac{3.4}{2.1}$ $\theta = 58.3^\circ$	Voltage
Phase Angle	$\sin \theta = \frac{V_L}{V_T}$ $\sin \theta = \frac{3.4}{3.996}$ $\theta = 58.4^\circ$	Phase Angle

R-L-C PHASE CHARACTERISTICS

A Series R-L-C circuit is connected and the voltages across all of the elements is measured. The Phase Angle between the Voltage and the Current is calculated using the Voltages, the Reactances and using the Lissajou Pattern techniques. The circuit Impedance is also calculated.

2. The A.C. meter is used to measure all of the circuit voltages. The results are tabulated below.

A.C. V_L	= 0.4 volts RMS
A.C. V_C	= 0.22 volts RMS
A.C. V_R	= 2 volts RMS
A.C. $V_{(L+C)}$	= 0.18 volts RMS
A.C. V_{in}	= 2.2 volts RMS

3. Is the circuit Inductive Reactance or Capacitive Reactance greater at this frequency?
The Inductive Reactance is larger than the Capacitive Reactance. This is true because the voltage across the Inductor V_L is larger than the voltage across the Capacitor V_C .

$$\tan \theta = \frac{(V_L - V_C)}{V_R} = \frac{(0.4 - 0.22)}{2} = \frac{0.18}{2} = 0.09$$

$\theta = 5.143^\circ$	CALCULATION BASED ON VOLTAGE MEASUREMENTS
------------------------	---

5. Calculations of Reactances at this frequency ($f = 2\text{KHz}$).

$X_L = 2 \pi f L = 2 \cdot 3.14 \cdot (2 \times 10^3) (50 \times 10^{-3}) = 628 \Omega$
$X_C = \frac{1}{2 \pi f C} = \frac{1}{2 \cdot 3.14 \cdot (2 \cdot 10^3) (0.25 \times 10^{-6})} = 318 \Omega$
$R = 3.3K$

R-L-C PHASE CHARACTERISTICS

6. Calculation of Circuit Impedance using the calculated values of X_L , X_C and R .

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(3.3)^2 + (628 - 318)^2}$$

$$Z = 3314 \text{ ohms}$$

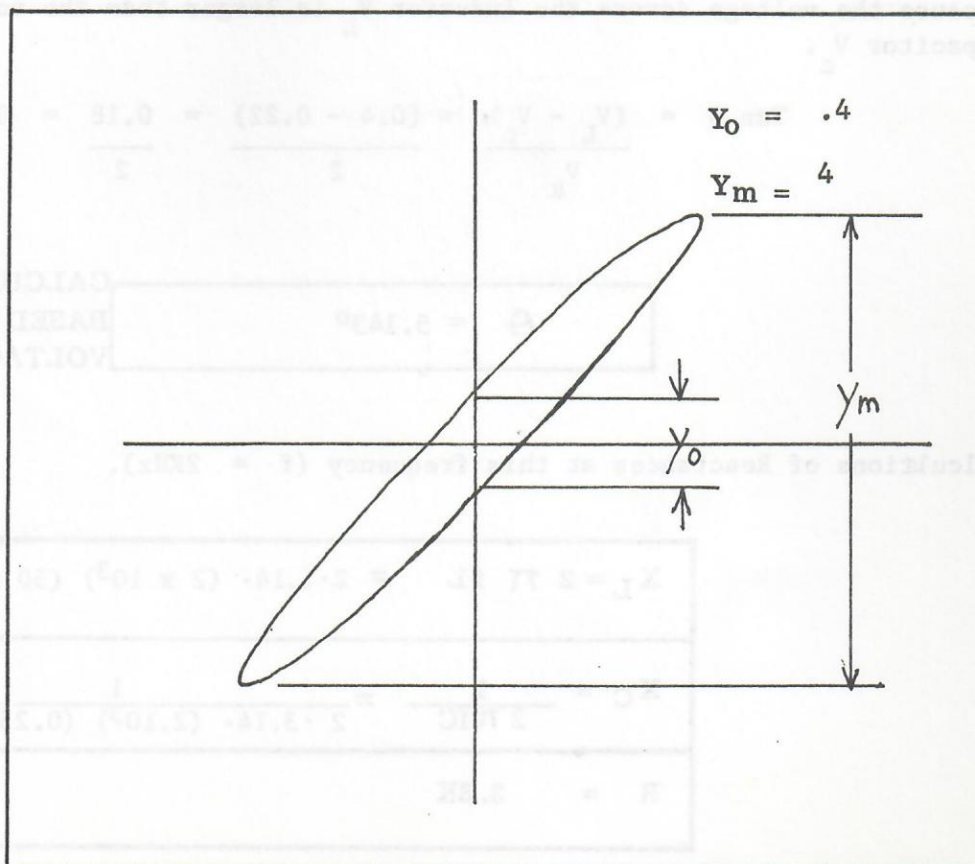
7. Calculation of Phase Angle using the Impedances X_L , X_C and R .

$$\tan \theta = \frac{(X_L - X_C)}{R} = \frac{628 - 318}{3300} = 0.093$$

$$\theta = 5.35^\circ$$

CALCULATION
BASED ON
CALCULATED
"REACTANCES"

8. Calculation of Phase Angle using Lissajous Pattern.



R-L-C PHASE CHARACTERISTICS

$$\sin \theta = \frac{Y_o}{Y_m} = \frac{0.4}{4} = 0.1$$

$$\theta = 5.7^\circ$$

9. Calculation of the Voltage across both L and C. The Voltage across the Inductor is 180° out of phase with the voltage across the Capacitor. Therefore, adding the vectors of these two voltages means that they must be algebraically subtracted.

$$V_x = (V_L - V_C) = 0.4 - 0.22 = 0.18$$

$$V_x = 0.18$$

How does the V_x calculation compare with the measured A.C. $V(L \& C)$? The values are the same.

Calculation of V_T - The Input Voltage Amplitude

$$V_T = \sqrt{V_R^2 + (V_C - V_L)^2} = \sqrt{2^2 + (0.18)^2}$$

$$V_T = 2.008$$

How does the V_T compare with the measured A.C. V_{in} ?

$$\text{Measured A.C. } V_{in} = 2.2 \text{ volts}$$

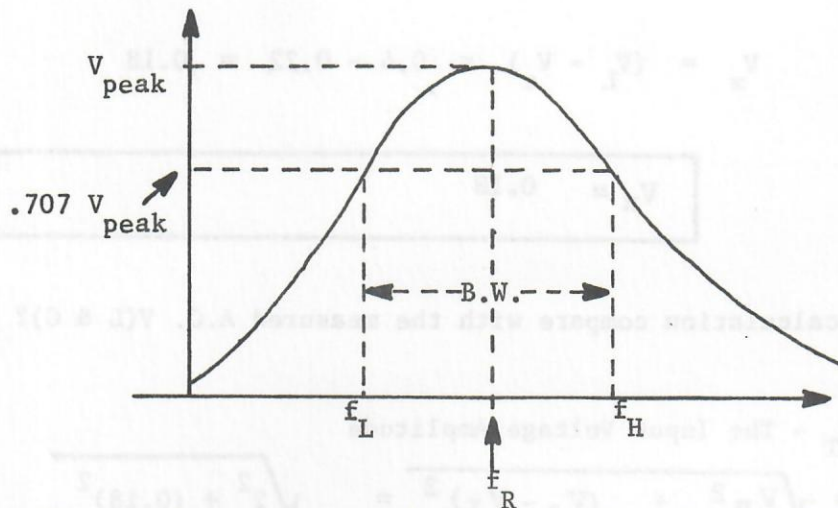
$$\text{Calculated } V_T = 2.008 \text{ volts}$$

$$\% \text{ Error} = \frac{2.2 - 2}{2.2} \times 100\% = 9.5\%$$

SERIES RESONANCE

The Frequency Response and the Q of a Resonant Circuit are determined. This experiment introduces the student to the concept of Resonance and Bandwidth and Q.

The output voltage will be a maximum at the Resonant Frequency and it will be smaller for all frequencies to either side of the Resonant Frequency. The curve of V_{out} versus frequency is shown below.



If the maximum amplitude of the output voltage is A , then $V_{out} = (0.707)A$ represents the $\frac{1}{2}$ power output points. This is derived in the following manner.

$$\text{Max Power Output} = \frac{A^2}{R}$$

$$\frac{\text{Max Power Output}}{2} = \frac{A^2}{2R} = \frac{(A)^2}{2} \cdot \frac{1}{R} = (0.707A)^2 \cdot \frac{1}{R}$$

$$V_{out} \left(\frac{1}{2} \text{ Power} \right) = (0.707)A$$

The points at which the V_{out} curve crosses the $0.707A$ voltage are called the half power or 3dB points. The frequencies at which this occurs are labeled f_L and f_H . The Bandwidth of the Resonant Circuit is given as:

$$\text{Bandwidth} = B.W. = f_H - f_L$$

The sharpness of the Resonant Circuit (i.e. the steepness with which the V_{out} versus frequency curve rises and falls) is taken as a measure of the Quality or Q of the circuit.

$$Q = \frac{f_R}{B.W.}$$

SERIES RESONANCE

The Q or Bandwidth of a Resonant Circuit is dependent upon the amount of "Loss" in the circuit. For a series circuit, the larger the series resistor the large the loss. As the loss increases so will the bandwidth and the Q will decrease.

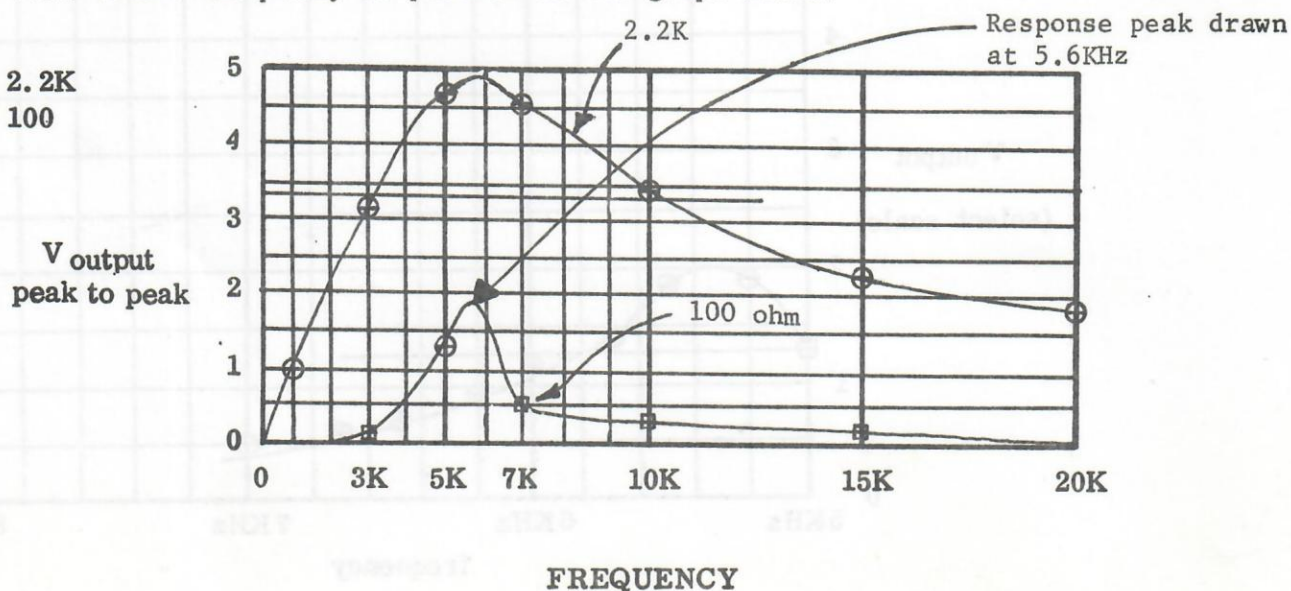
set	adjust input	measure	repeat measurement
frequency	V_{in} (pk to pk) (Switch A UP)	V_{out} (pk to pk) $R = 2.2K$ (Switch A Down)	V_{out} (pk to pk) $R = 100 \text{ ohms}$
200 Hz	5	0.205	0
500 Hz	5	0.5	0
1KHz	5	1.05	0
3KHz	5	3.2	0.2
5KHz	5	4.7	1.3
7KHz	5	4.6	0.5
10KHz	5	3.4	0.2
15KHz	5	2.3	0.1
20KHz	5	1.8	0

3. The frequency is carefully adjusted for maximum output voltage. This is the Resonant Frequency. The Resonant Frequency is recorded with the 2.2K resistor and the 100 ohm resistor.

for $R = 2.2K$ f_R	$f_R = 5.6KHz$
for $R = 100$ f_R	$f_R = 5.6KHz$

4. The V_{out} versus frequency is plotted in the graph below.

for
 $R = 2.2K$
 $R = 100$



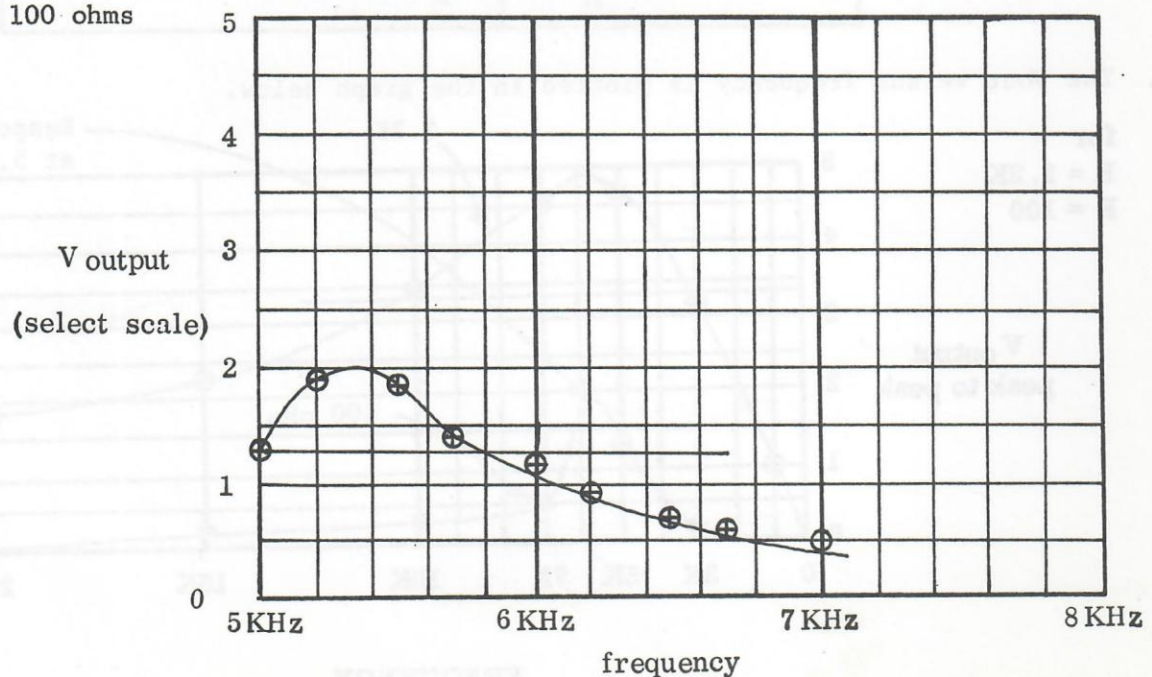
SERIES RESONANCE

5. The data taken in step 3 and plotted in step 4 for the 100 ohm circuit is not adequate to get a good idea of the shape of the V_{out} versus frequency curve. The data for this circuit is taken more accurately in this step.

set frequency KHz	adjust V input	read V output $R = 100 \text{ OHMS}$
5.0	5	1.3
5.2	5	1.9
5.5	5	1.8
5.7	5	1.4
6.0	5	1.1
6.2	5	0.9
6.5	5	0.72
6.7	5	0.6
7.0	5	0.5
7.2	5	0.46
7.5	5	0.4
7.7	5	0.38

6. The data from Table in Step 5 is plotted in the graph below.

$R = 100 \text{ ohms}$



SERIES RESONANCE

QUESTIONS:

1. How do these measured resonant frequencies (step 3) compare with the theoretical f_R?

The Measured Resonant Frequency is 5.6KHz
The Theoretical Resonant Frequency is 6.725KHz

$$\% \text{ Error} = \frac{6.72 - 5.6}{6.72} \times 100\% = 16\% \text{ Error}$$

2. Which Resonant Curve "width" is "narrower" or "sharper" (using R = 2.2K or R = 100)?

The 100 ohm Resonant Curve is the narrowest or sharpest.

3. The "width" of the curve is called the BANDWIDTH. As with the filter Cut-off Frequency, the bandwidth is measured at the half-power points or at 0.707 Voltage.

First determine the resonant peak Output Voltage for each case:

Use curve
from step 6.

for R = 2.2K	V _{peak} = 4.7
for R = 100	V _{peak} = 1.9

Determine 0.707 V_{peak} below :

for (R = 2.2K)	0.707 V _{peak} = 3.3
for (R = 100)	0.707 V _{peak} = 1.3

4. Draw these half-power voltages on the graphs and measure the Bandwidths (BW):

for R = 2.2K	BW = (10.1-3)KHz = 7.1KHz
for R = 100	BW = (5.8-5)KHz = 0.8KHz

Which bandwidth is narrower?

for R = 2.2K the Bandwidth is 7.1KHz
for R = 100 ohms the Bandwidth is 0.8KHz

The 100 ohm circuit has a much narrower bandwidth.

SERIES RESONANCE

5. The narrower bandwidth is generally better or more "selective" in frequency in radio circuits. A "Quality Factor" or "Q" of a circuit is defined as:

$$Q = \frac{fR}{BW}$$

Calculate the Q for both circuits:

for R = 2.2K	$Q = \frac{fR}{BW} = \frac{5.6}{7.1} = 0.788$
for R = 100	$Q = \frac{fR}{BW} = \frac{5.6}{0.8} = 7$

PARALLEL RESONANCE

A Parallel Resonant Circuit is built and tested. Also the Vout versus frequency curve is measured for various series resistor values and the Resonant Frequency and Q of the circuits are recorded.

The circuit used in this experiment consists of an inductor and capacitor in parallel fed by the Audio Sine Wave Generator through a Series Resistor. At resonance, the Inductive Reactance and the Capacitive Reactance are equal in magnitude and 180° out of phase. The Parallel combination at Resonance is:

$$Z_R = \frac{(-X_C)(+X_L)}{X_L - X_C} = \infty$$

Therefore at resonance the voltage across the parallel Inductor and Capacitor is maximum and the Vout will be maximum at this frequency.

The Resonant Frequency is the same as for the Series Resonant Circuit.

$$f_R = \frac{1}{2\pi\sqrt{LC}}$$

The Parallel Tuned Circuit has a Q and Bandwidth also. These are measured in this experiment. The Q is controlled by changing the value of the series resistor.

2. Measurement of Output Voltage versus Frequency.

set frequency	adjust V _{input}	measure V _{output} (R=1K)
200 hertz	5	0.46
500	5	0.9
1K	5	1.6
3K	5	4.2
5K	5	4.8
7K	5	4.8
10K	5	4.3
15K	5	3.3
20K	5	2.6

3. Determination of Resonant Frequency. The Input Frequency is adjusted until the maximum Vout is obtained. This is the resonant frequency.

$$f_R = 5.8\text{KHz}$$

PARALLEL RESONANCE

How does this compare with the theoretical Resonant Frequency.

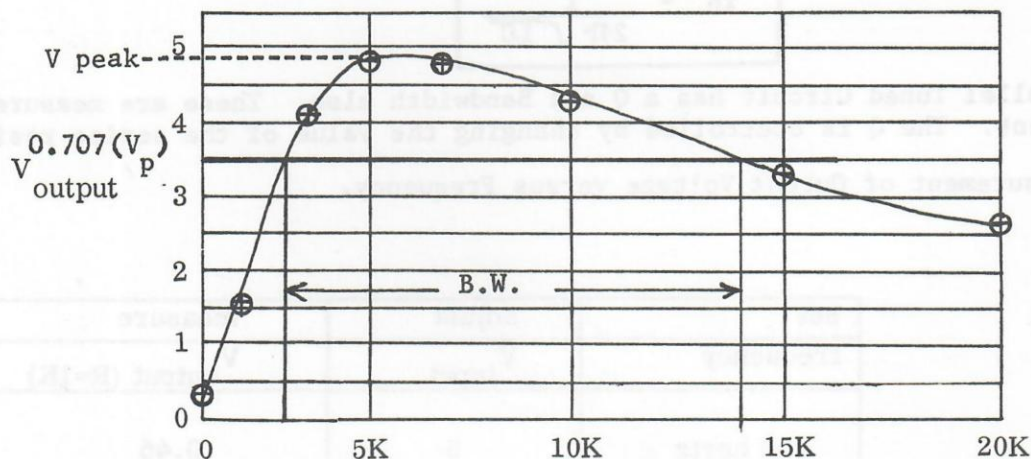
$$f_R \text{ (theoretical)} = 6,725 \text{ Hz} \quad f_R \text{ (measured)} = 5,800 \text{ Hz}$$

$$\% \text{ Error} = \frac{6725 - 5800}{6725} \times 100\% = 13.7\%$$

The output voltage at Resonance is:

At Resonance	$V_{\text{output}} = 4.85\text{V}$
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4. Graph of Voutput versus Frequency.



5. Bandwidth Calculation

Using the Graph in step 4, the 0.707 (Voutput at Resonance) level is marked. The Circuit Bandwidth is the frequency difference between the high and low intersection of the Voutput curve with this level (See graph Step 4)

Bandwidth = (14 - 2)KHz = 12KHz

6. Calculation of Q Factor

$Q = \frac{f_R}{\text{Bandwidth}} = \frac{5.8\text{KHz}}{12 \text{ KHz}} = 0.48$
--

for R = 1K, Q = 0.48

PARALLEL RESONANCE

7. Measurement of the Resonant Frequency and the Circuit Q for various Resistor Values. The circuit Q will be effected by the value of the series Resistor. The higher the resistance, the higher the Q of the circuit. When the Resistor value increases, the signal into the tuned circuit will decrease, but the losses also decrease and the Resonant Circuit Quality increases. Note that in this portion of the experiment we will take data only at the Resonant Frequency and at the half-power points.

Insert R	V _{out}	f _R	V _{in}	f _L (@.707V) Check V _{in}	f _H (@.707V) Check V _{in}	BW (f _H - f _L)	Q $\frac{f_R}{BW}$
10K	1 volt	5.9KHz	1.3v	5.2 KHz	6.9 KHz	1.5 KHz	3.9
56K	1	6.0KHz	2.4v	5.7 KHz	6.2 KHz	0.5 KHz	12
100K	1	6.0KHz	4.0v	5.8 KHz	6.1 KHz	0.3 KHz	20
1M	1	6.0KHz	2.4v	5.9 KHz	6.1 KHz	0.2 KHz	30

8. The resistor is removed entirely. Now only the losses in the reactors is present. This will result in the lowest loss and the highest Q circuit. The Bandwidth of the Parallel Resonant Circuit by itself will be very small. This tuned circuit will pick up the Resonant Frequency Energy in the environment, with no actual connection. This is the principal used to select radio stations with receivers. The receiver has a tuned circuit which Resonates at the Transmitter frequency.

$$f_R = 6.0 \text{ KHz}$$

$$f_H = 6.05$$

$$f_L = 5.95$$

$$BW = f_H - f_L = 0.1 \text{ KHz}$$

$$Q = \frac{f_R}{BW} = 60$$

RESONANCE TUNED RADIO

The Parallel Resonant Circuit is used to Receive Local Broadcast Radio Stations. This is an application of the Resonant Circuit.

The Radio Receiver in this experiment is a simple tuned circuit followed by a detector and a audio transistor amplifier. The Resonant Frequency of the Tuned Circuit is adjusted by turning the knob on the Antenna Coil. Q4 is an Emitter Follower. This acts as the detector diode and it provides a high impedance input for the Resonant Circuit so the Q will be high. The 2.2K resistor and 0.01 ufd capacitor are the envelope detector elements in the detector circuit. Q5, Q6 and the associated circuitry is a simple Audio Amplifier to improve the reception of the Radio.

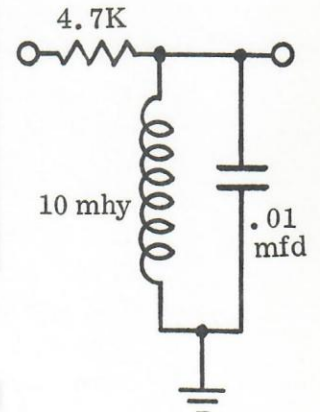
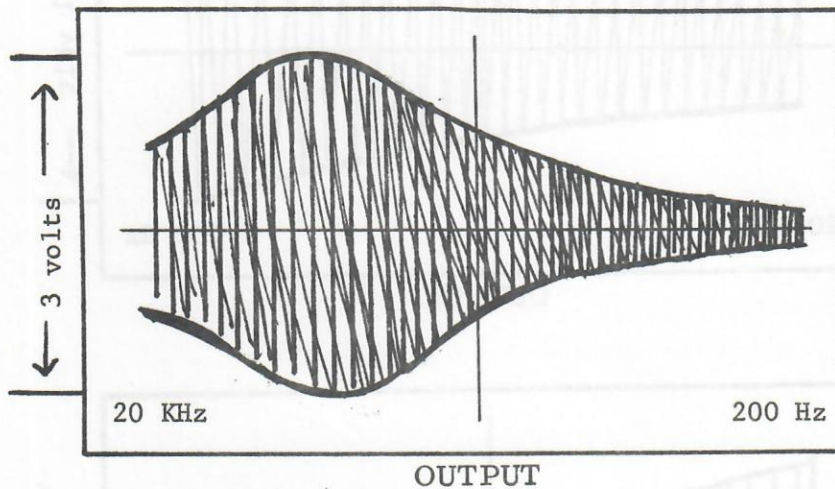
- The student will tune the receiver carefully throughout its range using the Antenna Coil Tuning Knob. This will be done with 150 pfd capacitor, 220 pfd capacitor and 330 pfd capacitor to assure tuning the entire A.M. Broadcast Band. Each station received will be noted with the Capacitor used, the station call letters and the frequency. The stations received will vary from locality to locality.

Radio Station	Capacitor Used	Station Call Letters	Resonant Frequency
1			
2			
3			
4			
5			
6			

FREQUENCY RESPONSE TRACER

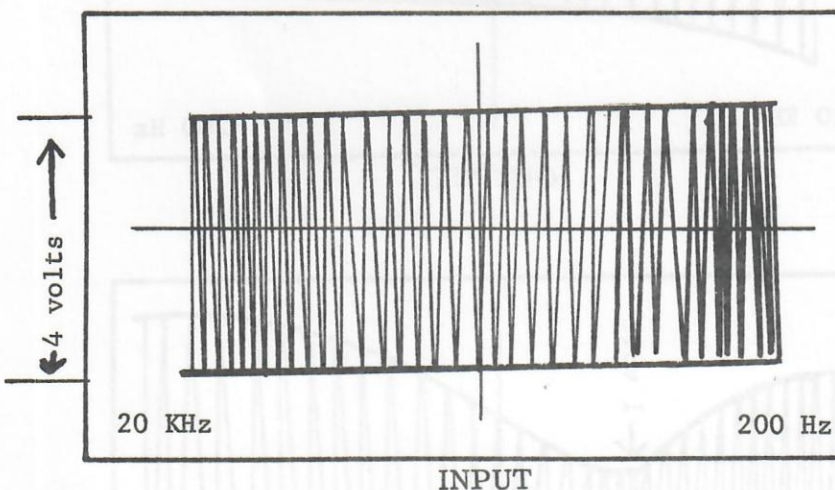
A "dynamic" or Sweep signal is used to trace the frequency response of a variety of reactive circuits. This is an opportunity to demonstrate the general frequency characteristics of resonant circuits and High and Low Pass circuits. It also serves to verify the frequency response curves generated in earlier experiments with point by point data.

2.

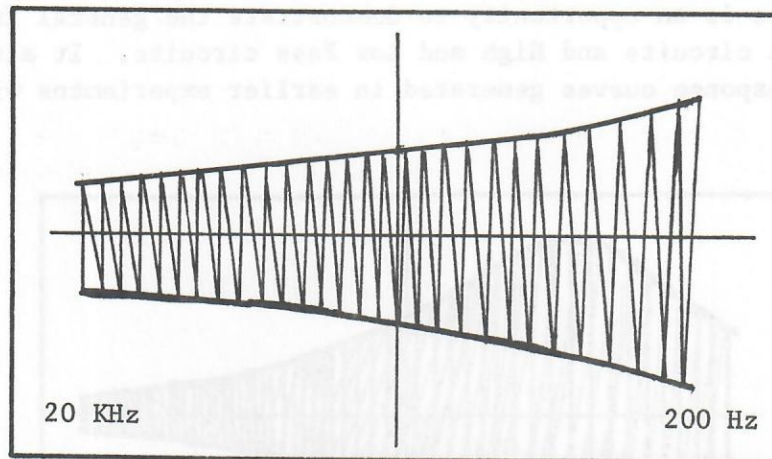


BAND PASS
FILTER

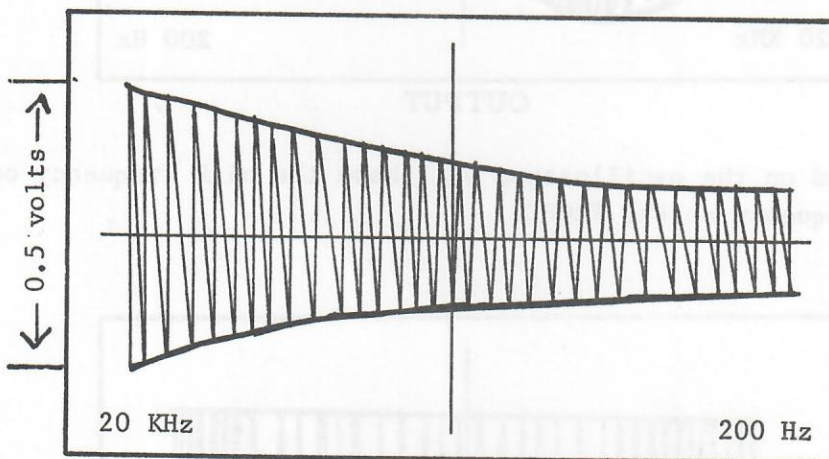
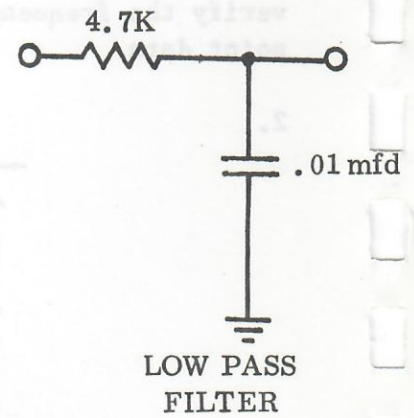
Note: The curve traced on the oscilloscope will have the high frequency on the LEFT and the low frequency on the RIGHT.



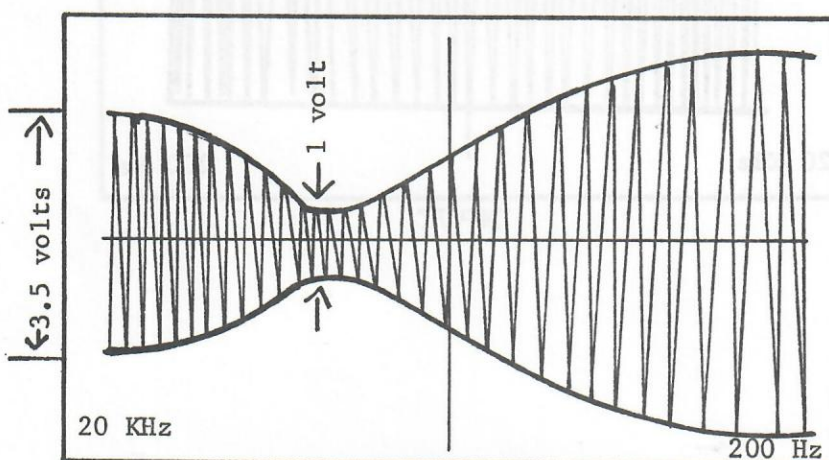
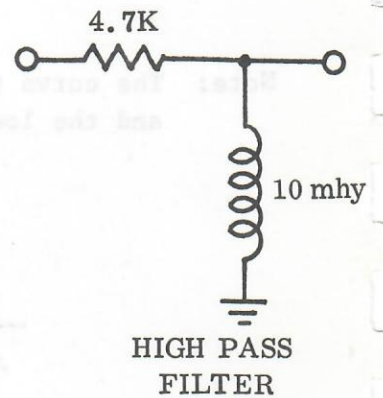
FREQUENCY RESPONSE TRACER



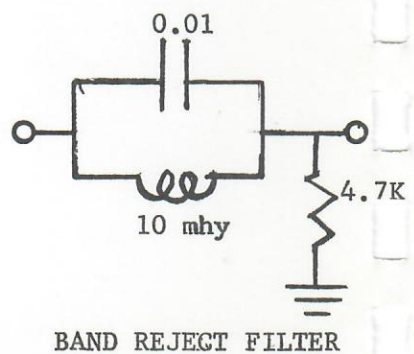
OUTPUT



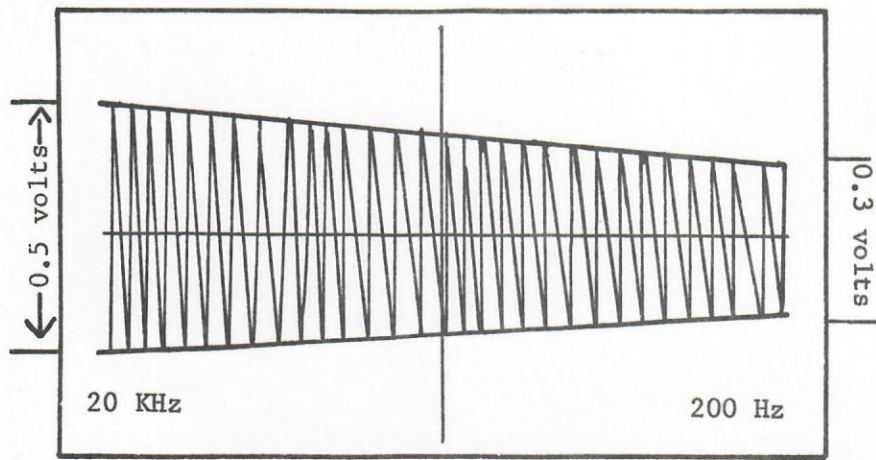
OUTPUT



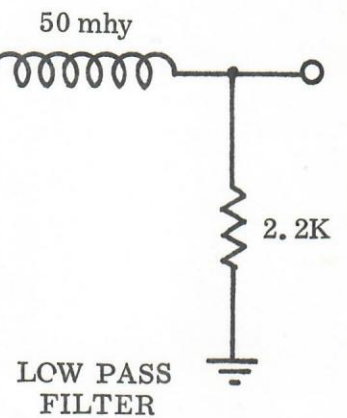
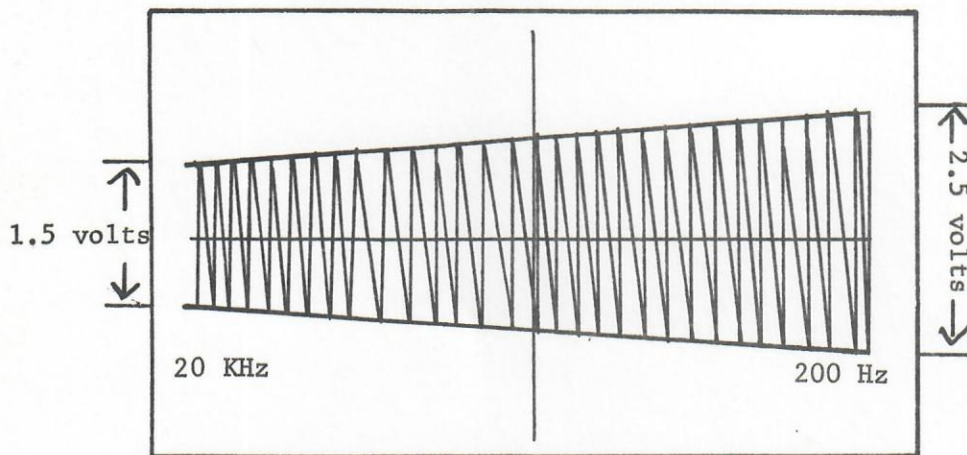
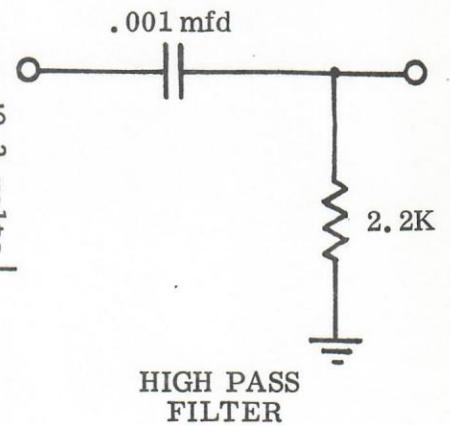
OUTPUT



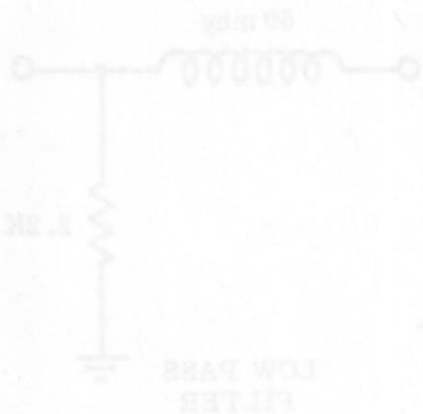
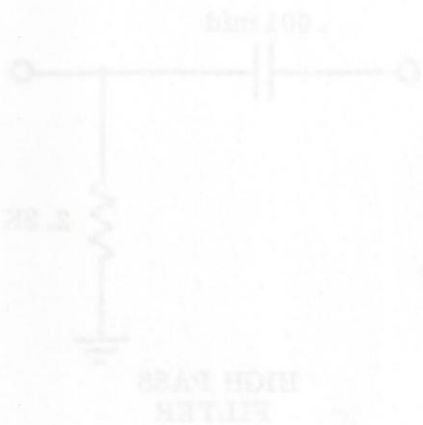
FREQUENCY RESPONSE TRACER



OUTPUT



PHOTOGRAPHIC RECORDING TRACKS



OUTPUT

